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THE TECHNOLOGY OF WELDING ELECTRIC ARC WELDING

BY

E. A. SATEL'

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SPRAVOCHNIK MASHINOSTROITELYA, V SHESTI TOMAKH

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Chapter III

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CHAPTER III

THE TECHNOLOGY OF WELDING

ELECTRIC ARC WELDING

Electric arc welding is a method of permanently joining metals and alloys with an electric arc melting locally the places of the parts to be welded.

Electric welding was invented in Russia, in 1882, by N.N.Bernados, who introduced the method of welding with carbon electrodes. The method of using metallic electrodes was first proposed by N.G.Slavyanov, in 1888.

The welding processes are subdivided into: manual, semiautomatic and automatic.

Sources of Electric Energy Required by Welding Arcs

Depending upon the number of units to be served, the transportability of the units and the nature of the work, electric energy is derived from the following sources: a) from direct and alternating current generators, b) from single operator or multioperator current generating units, c) from stationary or portable units and d) from generating units designed for manual and automatic welding.

Alternating current units are more economical and, therefore, more widely used. As an illustration, in manual welding with thickly coated electrodes, the consumption of electric energy is 3 to 4 kwh per 1 kg of molten metal, when AC current is used, compared with 6 to 8 kwh for DC current from a single-operator unit and with 8 to 10 kwh from a multioperator DC unit. Another example, in automatic welding with the use of flux, the energy required is: 2.5 to 3.5 kwh/kg when AC current is used and 5 to 7 kwh/kg, when DC current is used.

Direct currents are used in cases when the use of AC current is impossible, or where it is required by the process. Usually, DC currents are used in field work, in the welding with carbon electrodes, for the welding of certain special steels, for welding of thin metals and in the automatic welding of important parts, when the voltage of the local circuit varies considerably, and in a few other cases.

Direct Current Generating Units. The single-operator (or single-plug, or single-outlet) welding unit "SUG-2n", generating a maximum current of 250 amp with a "PV"* equal to 100%, consists of a generator having a common shaft with an electric motor. For moving to another place, the SUG-2n unit is built with wheels.

Other units of the single-operator type are the PS--300 and the PS-500. With a PV equal to 100%, the first one generates a maximum current of 280 amp, and the second unit generates a maximum current of 400 amp. The control limits are correspondingly: 80 to 400 and 120 to 600 amp.

Portable single-operator welding units, driven by an internal combustion engine, are used in places lacking an electric circuit. Welding unit SAK-2g-sh (250 amp with PV of 100%) and PAS-400-1 (400 amp with PV = 100%) consist of a generator and a gasoline engine mounted on the same base. The first unit is used for welding with a metallic electrode, the second, for underwater cutting.

The single operator, falling voltage characteristic type, generating unit SG-1000-11 with a power of 45 kw is designed to produce from 300 to 1200 amp.

Multioperator units SMG-3, 4, and 5 (rated currents 500, 1000 and 1500 amp) consists of a generator and electric motor mounted on the same base. These are stationary units. The PSM-1000, rated at 1000 amp is a portable unit.

In a multioperator, or multiplug welding unit, the number of plugs may be

* PV is an arbitrary name of the duration of a continuous welding job. It is expressed in percent.

calculated from the following equation:

$$n = \frac{i_g}{i_n k}$$

where i_g is the rated amperage of the generator at a load of long duration; i_n is the average current of the plug; k is the coefficient of the "same-timedness" and is usually assumed equal to 0.65.

The amperage of the plug in a multiplug is regulated by the welder by means of a ballast rheostat.

Alternating Current Generating Welding Units. The characteristics of transformers used in welding are shown in Table 1. The first four types (Table 1) are built with a separate control equipment to regulate the welding. The others are built as a single unit.

Transformers STE-23, 24, 32, and 34, also, STAN-0 and STAN-1 are designed for manual welding. The rest of the transformers shown in Table 1 are designed for automatic or semiautomatic welding under flux. The letter "D" in the transformer designations means that the transformer is equipped with remote control. If necessary, transformers of the same type may be joined in parallel.

The transformers described above are suitable for welding with a three-phase current.

For low-power electric arc (10 - 115amp) the plant "Electric" can furnish the PS-100 unit which generates a current with a frequency of 490 cycles/sec.

Metallic Electrodes and their Application in Manual Arc Welding

The basic requirements for electrodes are governed by the code GOST 2523-51 and known as "Steel electrodes for arc welding and metal fillering". This particular code deals with 13 types of electrodes used for welding structural steel having a tensile strength (of the seam and of the joined metal) from 34 to 100 kg/mm^2. The accepted designation is: E34-E100; included in this code are also four types of

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electrodes for welding recast heatproof steel designated as EP-50 – EP70; seven types for welding austenite heat resistant steels with symbols EA1, EA1B etc; four types

Table 1

Technical Characteristics of Welding Transformers

Type	Idle Voltage	Circuit Voltage	Power in kw	Welding amperage	Limits in regulating Welding Current in amps	Efficiency	Power Factor	Transformer Dimensions (of Base and Height) in mm	Control Equipment Dimensions (of Base) and Height in mm
STE-23	65	220,380,500	19.5	300	50-440	83	0.50	668 × 325 × 670	679 × 311 × 585
STE-24	65	220,380,500	22.5	350	100-500	80	0.52	646 × 314 × 660	594 × 320 × 545
STE-32	65	220,380,500	29	450	100-700	85	0.48	668 × 390 × 678	710 × 317 × 622
STE-34	65	220,380,500	30	500	100-700	81	0.54	690 × 370 × 660	669 × 320 × 545
STAN-0	63-83	220/110,380	8.7	140	25-150	83	0.51	698 × 429 × 485	
STAN-1	60-70	220,380	22	350	60-480	83	0.52	870 × 520 × 800	
TSD-500	80	220,380	42	500	200-600	87	0.62	950 × 818 × 1215	
TSD-1000-3	69,81	220,380	76	1000	400-1200	90	0.62	950 × 818 × 1215	
TSD-2000	72,80	380	144	2000	800-2200	90	0.65	1050 × 869 × 1288	

for welding high-chrome ferrite and ferrite-martensite heatproof stainless steels with symbols EF13, Ef17, EF25, Ef30; and ten types of electrodes for depositing surface layers of special properties with symbols ENP62, ENG35, etc.

The fabrication of coated electrodes is governed by GOST code 2246-54 which requires the use of steel wires with a diameter from 1 to 12 mm.

The length of welding rods depends on the diameter and alloy content.

In low-carbon and medium-alloyed steel wires having a diameter in excess of 3 mm, the electrode length, in most cases, is 450 ± 3 mm.

For quality seams possessing the required properties, heavily coated electrodes are in use by the machine building industry. Thinly coated electrodes are comparatively not in great demand. The field of application and properties of several widely used heavily coated electrodes is shown in Table 2.

For preliminary calculations, it may be assumed that most of the electrodes

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Table 2

Heavy-Coated Electrodes for Metal Depositing and Arc Welding of Structural and Alloy Steels

Electrode Trademarks	Electrode type as per GOST 9256-5	Fields of Application			
		Nature of Welded Steel	Service for which the Welded metal is Designed	Current and Polarity	Electrode wire as per GOST 2246-64
TsM-7 *	E 42	Low-carbon	Designed for severe tasks, operating with added static and dynamic loads at high and low temperatures	AC or DC	SV-08 SV-08A SV-15
MEZ-04 **	E 42	" "			SV-15
OMM-5	E 42				SV-08 SV-08A
UONI-13/45	E 42A	Low-carbon Low-alloyed	ditto	DC, reverse polarity,	SV-08 SV-08A
UONI-13/55	E 50A	Medium C low-alloyed		AC with oscillator	SV-15
TsU-1SKh	E 50A	Low alloyed SKL-4 type		DC with reverse polarity	SV-15 SV-08A
TsL-6	EP 50	Molybdenum boiler type (15M, 20M)	Steam lines, manifolds and boilers operating at temperatures up to 5[illegible]0°C	AC or DC	
Ts-2KhM	EP 55			DC, reverse polarity	SV-08
Ts-2KhM	EP 55	Chrome-molybdenum (15KhM)			
UONI-13/nzh	E[illegible] 1	Stainless chrome-Ni EZh-1 and EZh-2	Designed for severe tasks	ditto	SV-9Kh18N9 steel 1Kh13 and 2Kh13
ENTU-3	E[illegible] 1	Stainless	ditto	"	SV-0Kh18N9
TsT-1	E[illegible] 4	Heat-resist. austenite		"	
TsT-1 ***	EN[illegible]62	Metal deposits from ST-1 to ST-5 steels, forged instrument steel R18, operating without impacts		DC reverse polarity or AC	ditto

* TsM-7 electrodes, when coated heavier, are designated as TsM-75 which are able to effect speedy manual welding of butt and angle seams of low carbon steels

** The carbon content in wire SV-15 for electrode MEZ-04 should not exceed 0.15%

*** There are three varieties of TsI-1: TsI-1M having wire SV-08, Ts-1U with wire of carbon steel U9; and Ts-1L with alloyed steel wire 3KhV-8

Remarks: Electrodes Ts-1 are operated in the low position, all other - in any position

Electrodes Ts-1 TsI-1, TsM-7, OMM-5, TsL-6, TsU-2KhM, and TsU1SKh are designed by TsNIITMASh; electrodes NII, UONI-13izh, UONI-13/45, UONI-13/55, MVTU-ENTU-3 are designed by the Moscow Electrode Plant will be effective in welding at the low position, when the current is $i = 40d$, where i is the welding amperage; and d is the diameter of the electrode rod. Low position welding with TsM-7s electrodes is effective with a current up to 75d. For certain welding operations the use of the TsM-7s electrodes with a diameter of 8 mm will increase the productivity nearly 4 times, when compared with welding productivity of OMM-5 electrodes of 5 mm in diameter.

As to weldability, low-carbon steels are best. Certain structural steels (Grades 25, 15G, 15Kh, NL-2, SKhL-4 and others) are good for welding. Increasing the carbon and alloy content in steel makes it necessary to resort to certain corrective measures such as additional heat to 100-300°C, thermal treatment thereafter, making multilayer seams amidst unfavorable for that conditions, etc.

Electric arc welding of cast iron and bronze is used chiefly to correct a defective casting. When welding grey iron (heating it preliminarily to 400-500°C), the use of OMCh-1 electrode will insure good mechanical qualities to the deposited metal. The rod of electrode OMCh-1 is made of cast iron in accordance with the GOST code 2671-44 for welding cast iron rods. Monel-metal and copper-iron electrodes are used in welding of grey iron without the preheat. The seam produced by these electrodes is 50-60% as strong as the welded metal. Slight defects in high grade iron may be repaired with iron-nickel electrodes TsCh-3 producing metal deposits 50-75% as strong as the grey iron. A preheat of 300-500°C is necessary here.

The application of nonferrous electrodes is not sufficiently developed, although some electrodes for that purpose are in existence.

Thin coats are produced by immersion and thick coats by subjecting the electrodes to immersion and pressure.

For mass production of electrodes, the factory TsNIITMASh designed and manufactures an electrode coating machine with a capacity of 3-5 m per shift.

These are marketed by the Ministry of Heavy Machine Building.

Automatic and Semiautomatic Welding under a Layer of Flux

Automatic electric arc welding is widely developed in SSSR. Very promising for joining metals with a thickness of 60-250 mm and even thicker is the method of vertical electro-slag welding.

Equipment for Automatic Welding. An automatic welding unit consists of apparatus and mechanisms connected electrically and working in a definite consecutive order. The type of a unit to be selected depends on the design of the product to be welded, the distribution of the seams and the way the work is organized.

Welding Heads of TsNIITMASh Design. Welding heads designed by TsNIITmash, types A, B, V, G, have among other features a streamlined method of feeding the electrode regardless of the arc voltage. Many of these welding heads may be used suspended or pulled along and are also suitable for welding with a three-phase current.

Universal Welding Tractors Designed by TsNIITMASh and the Factory "Electric". The TsNIITMASh manufactures universal tractors type UT of which type UT-2000M and UT-1250 are in great use (the number after UT signifies the maximum welding current). The tractor-type welding unit UT-1250 is the lightest of all automatic welders and is, therefore, successfully used wherever frequent changes to manual operations are required.

The plant "Electric" is marketing welding tractors ADS-1000-2 which operate on the principle of the arc voltage automatically regulating the speed of feeding electrodes. The welding speed is controlled by the streamlined change of the electric motor carriage by means of a potentiometer.

Automatic Welding Units Designed by the Welding Institute E.O. Paton AN USSR. The products designed before were units type USA and self-propelling automatic type SAG, and from 1948, welding units type ABS.

When shifting the product during the welding process, the self-propelling

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mechanism may be removed from the automatic welding unit and the latter may be utilized as an overhead welding unit.

The welding tractor Type TS is a self-propelled unit. Widely used is tractor TS-17M which is suitable for a variety of welding operations. Tractor TS-24 is designed for welding with two consecutive arcs; tractor TS-26 - for welding with a current of 500-1500 amp using a 3-6 mm electrode, with a welding rate of 9-80 m/hr.

Table 3

Technical Characteristics of Automatic Welding Units

General Specifications	Welding Unit ABS	Welding Tractor TS-17M	Self-Propelling Welding Unit SSG-3 for Welding inside Ring-Seams	Universal Tractor UT-1250	Universal Tractor UT-2000M	Automatic Welding Unit ADS-1000-2
Electrode wire diameter, in mm	5-6	1.6-5	3-5	3-6	3-8	3-6
Current, in a	400-2000	200-1000	300-800	300-1250	300-2000	300-1200
Electrode feeding speed in m/min	0.5-3.75	0.87-6.6	1.5-3	0.53-3.3	0.55-14.3	0.5-2
Welding speed in m/hr	13.5-112	16-126	10-60	13-83	10.5-89	10-70
Method of regulating feeding speed	Changeable gears		Nonstage transmission			Electric motor
Weight, in kg	160	42	32	44	89	65

Special one, two and three electrode units and three-phase transformers are designed for electro-slag welding of metals 50-250 mm in thickness using a current of 500-700 amp with a speed of 1-2 M/hr all in one single operation.

<u>Special Welding Units</u>. In industry, already in use are self-propelling units for welding ring seams inside drums, for welding drilling bits, connections, pins, for welding with rivets, and also semiautomatic units.

Lately, considerably in use are hose-type semiautomatic and automatic welding units for welding with electrode wires of 1.6-2 mm in thickness with an AC or DC current of 200-700 amp. The Welding Institute is marketing semiautomatic hose-type units PSh-5 and PSh-54 with hose length of 3.5 m, equipped with special holders;

these are suitable for different operations. The plant "Electric" is marketing the ADSh-500 and PDSh-500 automatic hose-type units of which the first has a carriage for the electric conductor wires.

Technical characteristics of a few automatic welding units are shown in Table 3.

Basic Materials for Automatic Welding under Flux. The welded seam properties are determined by the composition of materials used, by the composition of the welded material and by the properties of the electrode wire and of the flux used.

For a given composition of the metal to be welded, seams of high quality may be obtained by correctly combining best suited electrode wires with best suited flux.

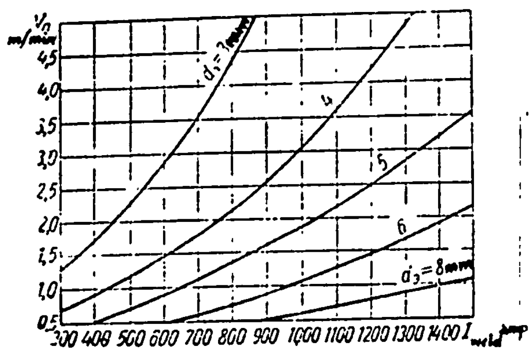

Fig.1 - Melting Speed (or Feeding Speed) of Low-Carbon Rods Depending on the Welding Current. By TsNIITMASh

Electrode Wires. For automatic welding with flux there is a variety of electrode wires with properties according to the code GOST 2246-54 (Table 4) and there are a few other types of wire.

Electrode wires or rods, are made 1-12 mm in diameter for automatic welding. The rod surface should be clean, free of rust, dirt and oil. The weight of a bundle of carbon steel rods is 20 kg for rod diameters of 1-2 mm, and rod with a diameter of 2.5-12 weight 60 kg.

The coefficient of metal depositing depends on many factors, and, as an average, in electric arc automatic welding of low-carbon steels, the coefficient is assumed to be 12-15 G/amp/hr. The melting speed of low-carbon electrode rods depending on the welding current for different diameters is shown in Fig.1. The melting speed of alloyed-steel rods is about 25% higher than low-carbon rods.

Fluxes. The fluxes used in industry are mostly molten and granulated silicates with a maximum size of particles equal to 3-3.5 mm. Depending on the granulating

Table 4

Welding Wire per GOST 2246-54 for Automatic and Semiautomatic Welding with Flux

Type of Steel	Basic Application
SV-8	For welding of steels MSt 1-4, St 3K, 3T, 4T also low-alloyed steels (20G, SKhL4) using a flux with a high manganese content, like types OSTs-45 and AN-348-A
SV-08A	Ditto, especially recommended for welding shaped joints
SV-15	For welding of steels MSt-1 to 3, St.3k, 3t, also a few low-alloyed steels 20G and SKhL 4
SV-10GS *	For welding of steels St. 1-4, with a welding speed of 100 m/hr and above, also low alloyed steels of high tensile strength
SV-15G	Electro-slag welding of 22 K steels
SV-18KhGSA	For the welding of steels 20KhGSA and 30 KhGSA, 20KhMA and 30KhMA
SV-12M	For the welding of boilers and pipes made of molybdenum steel
SV-0Kh18N9	For the welding of steel of the type Yal with heat treatment (hardening) to follow

* Welding wire SV 10GS with a low limit for silicon to 0.8% and manganese to 0.9% and with a top limit for carbon to 0.11% may be used for the semiautomatic repair of steel casting defects with the protection of carbon dioxide gas

method, the flux particles may be glass-like or may look like pumice. In certain cases of automatic welding unmolten (ceramic) fluxes may be used. This flux was developed by K.K.Khrenov, member of AN SSSR.

In automatic welding, the flux isolates the welding bath from being affected by the atmosphere and brings about a mutual metallurgical reaction.

The average required thickness of a flux layer above the welding bath and of the melting speed of the electrode is approximately equal to ten diameters of the welding rod. In general, the flux consumption is about equal to the welding rod consumption.

When the flux does not react with the welding bath elements, the composition of the bath may be calculated as follows:

$$(x) = n\,(x)_0 + m\,(x)_n,$$

where (x), $(x)_o$ and $(x)_n$ is the content of element "x" in % of the metal of the seam, of the metal to be welded, and of the welding rod; "n" and "m" are fractions of the metal and of the welding rod contained in the seam. These, in a usual single-arc welding, are correspondingly equal to 0.65 and 0.35. In automatic welding with the use of a three-phase current, "n" and "m" may be regulated by changing the operating conditions. The values of "n" and "m" in an electro-slag welding are equal to 0.4 and 0.6.

When, in addition to industrial fluxes (OSTS-45 and AN-348-A), it is necessary to use fluxes of other grades, consumer plants organize their own production of such fluxes.

When it is necessary to use fluxes other than used in industry, the consumer plants usually organize the production of their own fluxes. These may be, for example, fluxes resembling the TsNIITMASh type FTs-4 for a single-pass welding of very thick steels; FTs-7 for a multipass welding of thick steels with a three-phase arc and using slag; FTs-9 for hose-type welding; FTsL-2 for steels Grade Ya-1, and others. Very much in use for the puspose of melting flux in moderate quantities is the electric furnace developed by TsNIITMASh with a capacity up to 55 m/day using a current of 700-800 amp. The energy consumption is equal to 1000 kw/hr for each m of flux. For large quantities it is advisable to use the three-phase electric furnace marketed by the "Trust Electropech" able to handle a volume of 0.5 m of flux and having a melting capacity of 9.5 m/day. The moisture content of a flux should not exceed 0.1%. If the moisture content is large, the flux should be dried for

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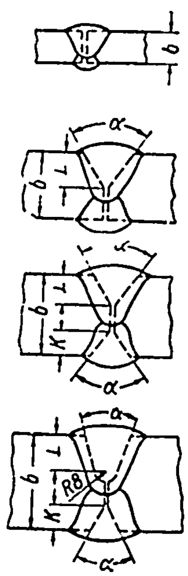
Table 5

Operating Conditions for Automatic Welding of Butt Joints (Data by TsNIITMASh)



Thickness of Material in mm	Sketch	Seam	Components: α and $α_1$ in degrees	Components: L & K in mm	Current in amperes	Voltage of the arc	Welding speed in m/hr	Electrode Diameter in mm
10		Main seam		-	720-750	38-40	45	5
		Added seam			600-650	38-40	55	5
15		Main seam			850-900	38-40	32	5
		Added seam			680-720	38-40	45	5
14		Main seam	80	6	830-850	36-38	25	5
		Added seam			600-620	36-38	45	5
22		Main seam	55	15	1050-1150	37-40	18	6
		Added seam			600-620	36-38	45	5
20		Main seam	60	10	1000-1050	40-42	16	6
		Added seam	60	5	850-900	40-42	18	5
45		Main seam	50	17	1200-1350	38-45	12	6
		Added seam	45	17	1200-1300	38-45	12	6
60		Main seam	55	23	1800	40	11	8
		Added seam	55	20	1650	38	16	8
90 **		Main seam						
		Layers 1 & 2	20	65	[illegible]	35-40	28	8
		Layers 3-15			1050	35-40	18	8
		Layers 16-22			1050	35-40	23	8
		Added seam (manual)	60	20	250	–	–	5

* α and L refer to the main seam, $α_1$ and K refer to the added seam

** Beginning with layer No 3-4, the electrode is shifted from the axis and is alternately placed at each edge with a clearance of 4 mm

Remarks:
1. For metals up to 45 mm thick, the flux used is OSTs-45 with 2.5-0.4 mm granules, for 90 mm thick - flux FTs-4 with 3.0-1.8 granules, for 90 mm thick - flux FTs-6 with 2.5-0.15 granules
2. The volume weight of flux FTs-4 is within 0.8-1.1 kg/dm^3

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2 - 2.5 hours under a temperature of 250-300°C.

Operating Conditions and Welding Joints in Automatic Welding. The amperage of the current, the voltage of the arc and the speed of welding are the paramount conditions for welding. Besides this, the shape and the quality of the welded seam depend on the composition condition and degree of granulation of the flux, the slope angles of the electrode and of the electrode and of the metal to be welded, the design of the welded joint and many other factors. A few of the conditions for welding operations are shown in Table 5.

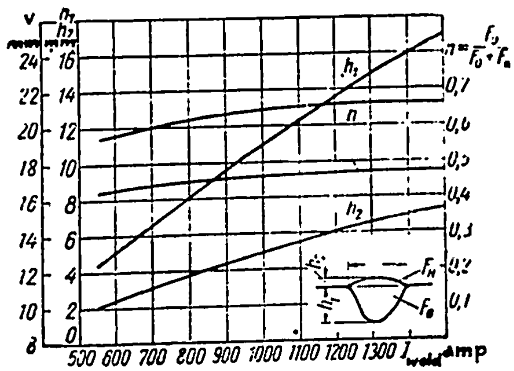

Fig.2 - The Effect of the Welding Current on the Cross Section of the Seam and on the Part of Welded Metal (n) in the Seam. (By TsNIITMASh)

The outlines of the molten zone depends on the operating conditions at welding, with the magnitude of the electric current being the main factor, as shown in Fig.2. The research made by TsNIITMASh and by the Welding Institute AN USSR established the fact that the relationship existing during the depositing of molten metal may be considered as applicable, more or less, when depositing butt seams or angular seams.

The type of seams in automatic welding with flux is the same as in manual work, that is, butt, lap and angular seams are used in both cases.

Certain features, specific to the welding with flux method, such as deep penetration, the fluidity of the metal bath, etc, present the opportunity not attainable in manual welding (examples: joints by very deep seams, by electro-weld rivets, etc).

To prevent the liquid metal flowing through loosely joined parts, the following methods of automatic butt welding are used:

1. A preliminary welding done manually makes it possible to weld the main seam in an assembly of parts with a clearance between two parts to be joined. The preliminary seam should be made with thickly coated electrodes of the type E42. The manual preliminary welding is used as an addition to the automatic welding of metals 10-90 mm in thickness.

2. A preliminary automatic welding is best recommended for joining plates 10-90 mm in thickness. The clearance between the edges, in this case, should not exceed 0.5-1 mm. When welding a round seam in a thick-walled drum of more than 1 m in diameter, it is necessary to do in several passes using a 1000 amp current. The same method should be applied in welding longitudinal seams, if metal thickness exceeds 50 mm. For automatic welding of metals thicker than 20-30 mm, it is advisable to use a three-phase current which can bring a saving of nearly 25% in energy consumption and can effect a saving in time of almost 1.5-2 times.

Automatic butt welding on both sides of steel 30-50 mm thick is being done in some plants. In this two-sided welding the clearance between edges is kept at 6-10 mm, the current is 900-1200 amp and the welding speed is 16-9.5 M/hr.

3. Welding with the use of a copper underlayer is mostly used in welding metals 2-6 mm thick. This method requires close contact of the metal with the copper lining all along the entire length of the seams. For this reason it is recommended when the precision of the assembly is high.

4. Welding on a flux underlayer will produce a lower precision in an assembly. To obtain a good seam formation in a single-pass welding of the bottom side, it is advisable to have some kind of a device to exert pressure on the flux. In a two-sided welding of heavy materials it is allowed to press the welded edges to the flux, though it may be done at the expense of the product weight.

5. Welding on the remaining steel underlayer when joining metals 2-6 mm thick is used when the operating conditions for which the product is designed are not hindered by the presence of the liner welded under the seam. The underlaying liner

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used is 0.5δ in thickness and $4\delta + 5$ mm wide, where "δ" is the thickness of the welded metal in mm. A variety of this method is the locked (closed) joint widely used in welding ring-type seams of cylindrical products, 130-300 mm in diameter.

For an electro-slag welding the butt ends of the product are assembled with a clearance of 24-26 mm between the parallel edges. The welding bath is kept in place by two water-cooled copper strips which are moved along the butt joint.

In a single-pass automatic welding of angular seams the calculated size of the seam may be assumed to equal toe size of its arch. In this manner, it may be assumed that an automatically welded seam is by 40% stronger than a seam welded manually. To obtain equally strong angular seams it is necessary, in manual welding, to deposit twice as much of molten metal as would be necessary in automatic welding. Interrupted type of angular seams are sometimes substituted by dotted seams welded by hose-type semiautomatic units having a capacity of 30-40 dots/min.

In automatic welding of angular joints, one of the plates may be placed horizontally and at an angle. In the first case the electrode is held at an angle of 45° with the horizontal plate, in the second case the electrode is held vertically.

Welding in the lower position of one of the welded plates simplifies the design of the layout and saves time when edging or angular seams are required.

A lower position single-pass welding of angular seams makes it possible to obtain seams with an arch size of up to 10 mm. When welding with the plates inclined at an angle, the size of the seam is not limited.

Besides the welding of low-carbon steels the automatic method is also applied in welding alloyed steels of different grades, with the operating conditions for low-alloyed and low-carbon steels being nearly the same. The properties of the seams on low-carbon and on many akloyted steels answer the requirements for products made of the same materials.

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Electric Arc Welding with Melting and Nonmelting Electrodes with Protection by Gas

Arc welding using a carbon electrode is not widely developed in industry, although, in many cases, the capacity would be higher than in welding with a metallic electrode. Especially advisable would be the use of carbon electrodes in welding joints not requiring added material, in cutting, in hot welding of cast iron and in welding of nonferrous metals. The strength of the metal seams of welded nonferrous materials is as follows: up to 15 kg/mm^2 for magnesium alloys, equal to the ultimate strength of aluminum weldings, 55-70% of the ultimate strength of duraluminum. In two-sided welding, it is possible without treating the edges to join steel plates up to 18 mm thick. Due to the stability of the arc, this method is easily mechanized and made easy for automization.

The operating conditions for manual and automatic welding with carbon electrodes differ little from another, however, with favorable conditions, one welder can attend 2-3 automatic units.

In industry, lately, is developed the automatic welding under flux by carbon electrodes (designed by MBTU) and by tungsten electrodes (developed by MATI). Of the metals welded by these electrodes are: nonferrous metals such as copper and copper alloys, aluminum and aluminum alloys; also differing metals, such as brass and steel, copper and steel and many others.

The use of automized argon-arc welding of nonferrous metals and of stainless steels by melting and nonmelting electrodes is now widely applied, and so is the use of these electrodes in welding copper in the presence of nitrogen.

Great potentialities may be expected from the new and effective method of automatic and semiautomatic welding of steel by melting electrodes with a carbon dioxide gas protection. This method was developed by K.B.Lyubavskiy and N.M.Novozhilov of TsNIITMASh. The TsNIITMASh also developed the hose-type semiautomatic unit for the repair of defects of steel castings. This unit is known as PEGSh-1. For welding under the protection of carbon dioxide gas the semiautomatic

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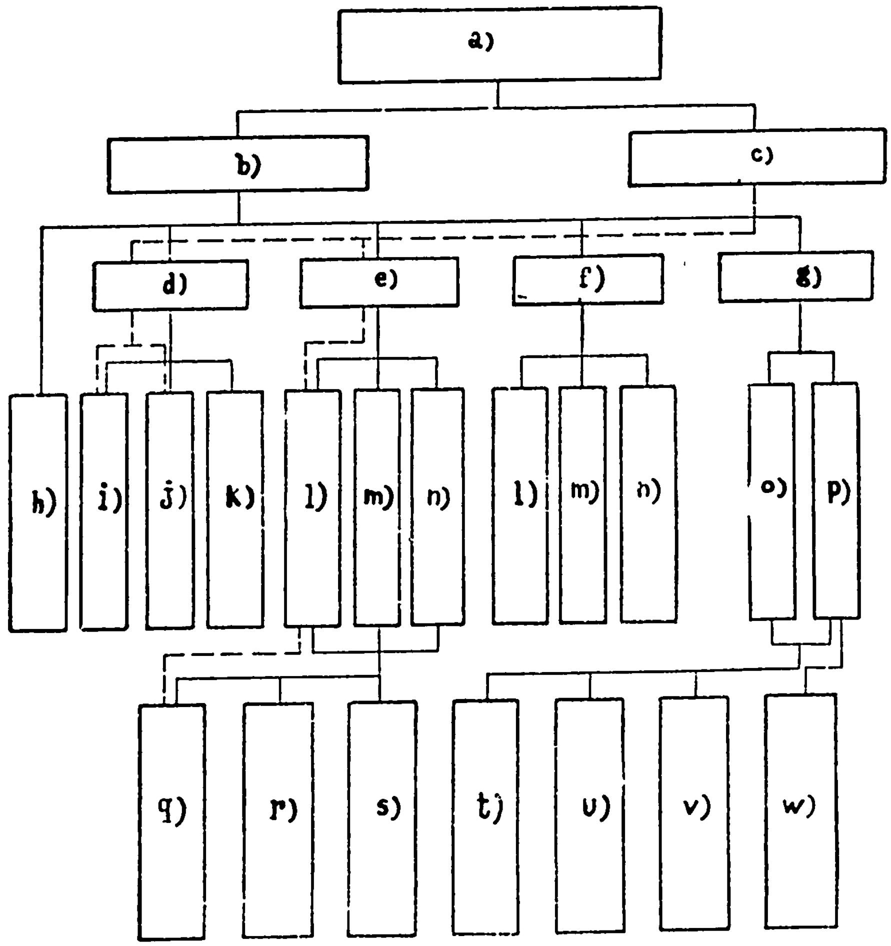

Fig.3 - Classification of Basic Methods of Contact Electrowelding

a) Contact welding; b) With AC; c) With accumulated energy; d) Butt welding; e) Spot welding; f) Relief and T-shape; g) Rolling; h) Method of A.M.Ignatyev; i) Resistance; j) By melting; k) By melting with a preheat; l) With a continuous flow of current; m) Multiimpulse; n) With heat treatment; o) Interrupted; p) Continuous; q) Two-sided single dot; r) Single side single dot; s) Single side two dot; t) Two sided; u) Single side (1 seam); v) Single sided (two seams); w) Butt roller

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PSh-5, PSh-54 and PDSh-500 may also be used.

CONTACT ELECTROWELDING

The basic methods of contact welding are classified as shown in Fig.3. Machines for contact welding are equipped with single-phase transformers which supply the welding circuit with a large current from a low voltage line. The transformer is usually connected to a three-phase 50 cycle circuit with the phases unevenly loaded. A 300 cycle current is used, but seldom, for a two-dot inside welding, which allows the use of smaller dimensions for the unit. A 2.5--3 cycle current is used at times, this increases the efficiency and cos φ of the machine, which in its turn makes dot-welding of thick products easier. When the current frequency is not one used in industry, the transformer is supplied with a single-phase current by means of a rectifier (machine or vacuum tube), producing an even load on the three-phase circuit.

Accumulated energy is used in dot-welding of light alloys, also in dot and butt welding of very small ferrous or nonferrous parts. The machine gets the current from a three-phase circuit through a straightening device with little energy used and with phases evenly loaded. The amount of energy furnished by the machine is stable. This insures a constant amount of heat emitted and a uniform quality of the joints. The energy accumulates in the electric field of the condenser or in the magnetic field of the specially designed transformer, which are a part of the welding unit. At times, the machine is fed by a special generator which accumulates the energy in the flywheel.

The basic methods used in contact welding are shown in Fig.4.

Butt Welding is performed by the resistance method or by depositing of molten metal. In either case, the welded parts (1) and (2) (Fig.4a) are tightly held in copper electrodes (lips) (3) and (4) which act as the right and left squeezers. The right squeezer is installed on a movable plate (support) (5) which moves with

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a force P in the direction of the stand (6); the left lip is placed on a stationary plate (7). The transformer (8) is connected with the plates by means of a flexible

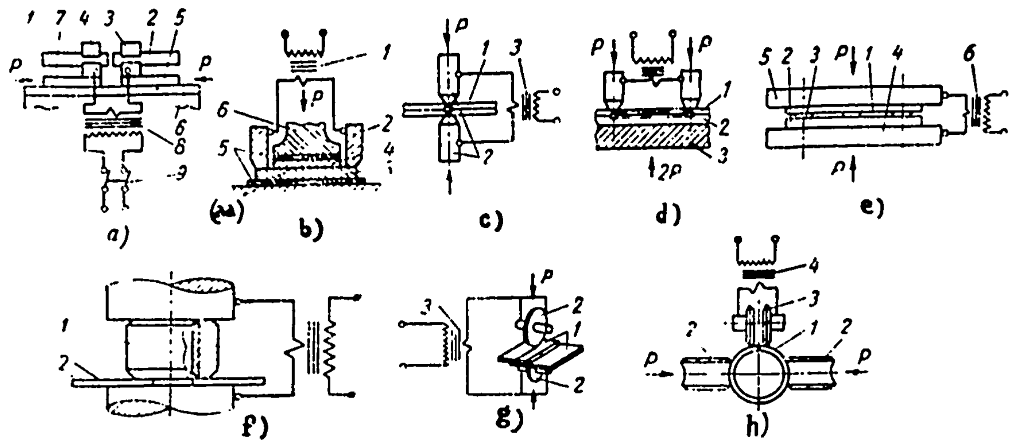

Fig.4 - Predominant Methods in Contact Welding

(aa) The plane of welding

tube and is supplied with electricity through a connecting device (9).

The resistance method of welding is carried out without melting of the metal in the butts. The parts to be welded are brought together until they touch each other and are pressed together with a force P, after which the current is turned on, heat appears in zone of contact and the parts become welded.

The welding by the method of melting is essentially as follows: With the current turned on, the parts approach each other until an electrical contact is established at some point at their butt ends. A quick heating develops at the point of contact which melts and partially vaporizes the metal, part of which is thrown out in splashes. As the parts are brought nearer to each other, new points of contact are established which generate more heat. After sufficient heat is developed and thin molten streams of metal are formed, force P is quickly applied and the upsetting of the butt ends takes place. With the upsetting of butt ends, the molten metal is pushed from the clearance between the two parts and welding takes place. Parts having a large cross section before the melting are heated by current impulses by short circuiting the ends of the parts. The force for upsetting is tramsmitted to the welded parts by friction forces which are developed in the squeezers; in short pieces, the upsetting force is partially taken up by the squeezers unloading device.

In welding by the Ignatiev method, the current from transformer (1) to be electrodes (2) is flowing parallel to the plane in which parts (3) and (4) are to bwe joined (Fig.4b), and which are located between asbestos linings (5). After a uniform heating to $1200-1280^{\circ}$C, the parts are pressed together by press (6) and are welded.

<u>Spot Welding</u> is either two-sided or one-sided. In a two-sided welding, parts (1) (Fig.4c) are squeezed between the electrodes (2) with a force P. After connecting transformer (3) of the two-dot machine, the central portion of the metal squeezed between the electrodes is quickly heated and melts, after which the current is turned off and force P is removed. Upon cooling, a welded dot is formed together with a very small cast ball. In a one-sided welding (Fig.4d), the current is distributed between the upper and lower parts (1) and (2). The welding is effected by the current flowing through the lower part into liner (3).

<u>Relief welding</u>, in which several dots are welded simultaneously, is a variety of the spot welding. The parts to be welded (1) and (2) (Fig.4e) are closely touching each other at the projecting points of the relief (3), which (the points) are preliminarily stamped at places to be welded. The parts are preliminarily squeezed with force P between the stationary plate (4) and the movable vertical plate (5). The current from transformer (6) heats the parts and welding takes place after the parts are flattened by force P.

In T-shaped welding, small parts (lugs, pins, etc) are welded to a plate or sheet (Fig.4f).

Good results are obtained by localizing the heating and the welding in places, where the ridges have been produced by stamping, or where the ridges have been

Table 6

Fields of Application for Various Methods of Contact Electrowelding

Welding Method	Field of Application
Butt Welding	
Elongation of elements of construction (welding of rails, pipe coils, steel strips in rolling mills, frames for reinforced concrete, etc. Joining parts of different metals and alloys (welding of instrument steel with other grades of steel, heat resistant steel welded with other grades of steel in the production of engine valves, etc. Formation of parts with a closed contour (welding of wheel rims, flanges, chain links, etc). Forming complex products from parts of simple shape (repair welding of locomotive draw-bars made of rolled and forged shapes).	
1. Butt welding by resistance method	Welding of wire products made of steel, copper, aluminum, chain links (up to 19 mm).
2. Butt welding by melting without preheat	Welding of steel plates, tubes and assemblies from materials of different shapes which allow quick heating and cooling; also large chain links and light alloys.
3. Butt welding by melting with a preheat	Welding of parts having a large cross section (rails, thick walled tubes, alloyed steels suitable for intensive tempering, instrument steels, etc.
Welding by the Ignatyev Method	
In producing instruments	
Spot Welding	
Joining overlapped steel plates, steel and nonferrous shapes Forged-welded assemblies and frames welded to sheets. Welding of rods to form a net Welding of metal parts of reinforced concrete.	
1. Continuous* (most widely used)	Welding of low carbon, low-alloyed nontempered steels and nonferrous metals
2. Multiphase*	Welding of steels more than 6 mm thick
3. With heat treatment*	Welding of carbon and alloyed steels for products designed for hard operating conditions.
4. Two-sided, single dot	Most widely used method of welding of small and medium forged welded assemblies
5. One-sided, single dot	Used in combination with shifting devices ("pistols", "levers") and as part of a multidot machine in producing dot welds consecutively

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Spot Welding	
6. One-sided, two dots	Used in welding large-size assemblies (in car building) and in multidot machines producing dot welds consecutively.
Relief and T-Shaped Welding	
Welding of small low carbon parts in mass production (automobile industry)	
Roller Welding	
Welding of tanks, packing material, fire extinguishers, etc.	
1. Continuous*	Used occasionally in welding thin sheets (up to 1 mm thick) of low carbon steel, also in butt-roller welding of tubes (see below) with a speed over 6 m min.
2. Interrupted*	Most widely used method of roller welding of parts made from low carbon, stainless and heat resisting steels, from aluminum and from certain copper alloys.
3. Two-sided	Welding of small and medium size parts (most widely used universal method).
4. One-sided, one seam	Used occasionally in welding of thin wrapping sheets of large size.
5. One sided, two seams	Used ocassionally in mass production.
6. Butt roller	Used in production of thin-walled tubes of carbon and low carbon steels.

* These methods of welding may be effected in various ways (two-sided, one-sided, etc., see Fig 3)

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treated mechanically.

Roller Welding is performed on a machine in which the electrodes are usually rotating disks. The parts to be welded (1) when assembled are overlapping each other (Fig.4g) and are squeezed between the electrodes (2) with force P. The current from transformer (3) flows to the electrodes which are made to rotate (one or both) by a special driving device. After the parts are squeezed and the current is turned on at exactly the same moment, the electrodes begin to rotate and thereby move the parts to be welded. Roller welding may be continuous or interrupted. In a continuous roller welding, the current remains on during the entire time it takes to weld each seam. In the interrupted roller welding, the short-life current impulses follow one another with a definite duration in time. The result is a continuous row of dots forming a seam.

Butt-Roller Welding (Fig.4h) is used in the manufacture of pipes. The material to be welded (1) is placed in the bending portion of the pipe-welding machine, where it is bent to the proper diameter, with the open ends on top, and able to move along the axis. The pressure required for welding is imparted by force P to the rollers (2). The electric current to the welded parts is furnished copper electrodes (3) which roll along on top of the pipe. The electrodes are connected to transformer (4).

The fields of application of the various methods of contact welding (using AC current) are shown in Table 6.

Equipment Used in Contact Welding

General Features and Important Parts. The simplest electric wiring diagram for the contact-welding machine is shown in Fig.5.

This diagram shows: 1 - circuit breaker, 2 - fuses, 3 - magnetic contactor, 4 - starting button, 5 - section-reversing switch, 6 - transformer, 7 - electrodes, 8 - part to be welded.

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In low-power machines, the contactor is sometimes substituted by a mechanical switch, which is a bad substitute since the contact points are quickly burned. In high-power machines, it is substituted by an ignitron electronic tube acting as a switch and which tegulates with precision the duration of the heating required for welding and also regulates the amount of energy required.

The amount of heat generated in contact welding is: $Q = 0.24\ RI_2^2\ t_{sv}$, where R is the active resistance of the welding portion of the circuit located between the electrodes and is measured in ohms; I_2 is the current in the welding circuit, in amp; t_{sv} is the duration of the current, in sec.

The energy required during the short period of effective welding is:

$$P_{\kappa r} = \frac{I_2^2 Z}{1000}\ \kappa va,$$

where Z is the full resistance of the machine and of the welded part.

The operating conditions of the machine depend on the duration during which the current is on:

$$PV = \frac{t_{sv}}{t}\, 100\%,$$

where t_{sv} is the duration of the current during the welding; t is the full duration for the entire welding cycle.

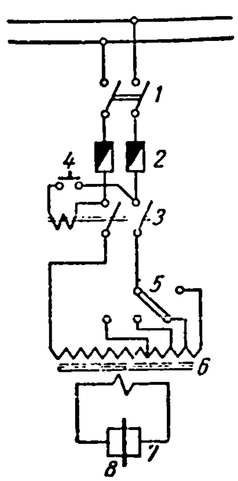

Fig.5 - Electric Wiring Diagram of a Machine for Contact Welding

The rated power P_{nom} is shown on the machine label. The rated Pv of the transformer is shown on its label. P_{nom} is the power developed without heating any part of the machine when welding during the duration (the one before the last) of the current furnished by the transformer.

The maximum welding current is equal approximately to:

$$I_{2\,(\max)} = k\,\frac{P_{nom}}{E_{2\,(\max)}}.$$

where $E_{2\,(max)}$ is the greatest stress during the idle performance of the transformer; k is a coefficient, usually equal to 1.2 - 1.5. When E_2 remains unchanged, the current I_2 decreases as the cortour of the machire area increases (for example with the increase of the effective distance L in Fig.7). This is due to the increasing induction resistance and to the introduction of a ferromagnetic material in the contour.

The machines are subdivided into: 1) butt-welding; 2) dot-welding; (including presses for relief welding); 3) roller welding.

Butt-Welding Machines. The basic features of such machines are described in Table 7. The low-power automatic machines ASIF-5 are designed for resistance welding; medium-power machines with a lever drive, the ASIF-50 and ASIF-75 are basically designed for welding by melting with the use of a preheat; the high-power RSKM machires are designed for automatic welding by melting with a preheat. Also in the market are MSM machines (Fig.6) with a power of 150 kv-amp and higher driven by an electric motor; the hydraulically driven MSG machines with a power of 300-500 kv-amp, suitable for operations with a preheat when operated manually. Also, the TsNIITMASh designed machines for butt welding of thin sheets (δ = 2-4 mm) with a width from 450 to 1500 mm, also , machines for butt welding of ribbons (MSL-200) and for welding pipes and tubes, etc.

Dot-Welding Machines. Basic specifications for dot-welding machines are shown in Table 8. Among those widely used in mass welding are machines type MTP with a power of 75-200 kv-amp (Fig.7). Automatic dot-welding machines make it possible to turn the current on and off just at the required moment and, also to remove the power from electrodes.

There are also overhanging machines of the type MTRG with a power of 75 kv-amp

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and above, equipped with a pneumatic-hydraulic drive, designed for welding steel parts of 3 + 3 mm thick and for welding rod to the shape of a cross.

Table 7

Basic Features of Machines for Butt Welding

Specifications	Machine Types				
	AZIF-5	AZIF-50*	MSM-150	MSGA-300**	RSKM-320U
Primary voltage, in v	220; 380	220, 380	220; 380	380	380
Rated power, in kv-amp	5	50	150	300	320
Nominal duration of the current (Pv), in %	25	25	20	30	25
Control limits of the secondary voltage, in v	1.16-1.74	2.9-5.0	4.5-7.8	5.4-10.8	4.7-10.5
Maximum welded cross section in continuous welding of low-carbon steel, in mm^2	60	400	750	4000	6000
Number of weldings attainable in 1 hr	40-100	30-50	110	30	10-15
Maximum weldability cross section for cyclic work in mm^2	100	800	2400	6000	10,000
Maximum operating principle	Automatic	Nonautomatic	Automatic		
Maximum distance between plates in mm	14	40	100	200	100
Maximum upsetting force in kg	150	2500	6500	16,000	25,000
The upsetting mechanism drive	Spring	Lever	Electric	Hydraulic	Electric

* Similar machines ASIF-75 are equipped with 75 kv-amp transformers with E_2 = 3.5 - 7.0 v

** A similar machine MSGA-500 is rated 500 kv-amp

In the automobile and freight car building industries, besides universal-type single-dot machines, in use are also two-dot and multidot machines for one-side welding and a variety of portable devices (levers, jacks, etc). Very large pieces of sheet metal and of stamped profiles are assembled on a conveyor which is part of a welding installation.

The one-dot machine MTPCH-250 operating on a low frequency (2.5-3 cycles) is used for welding steel up to 12 mm thick. Special multidot machines are used for welding of metal network and carcasses. In the welding of light alloys, besides powerful AC machines, in use are also machines operating on accumulated energy (condensor and electro-magnetic), also, machines (MTIP-600) operating only by the impulse of a compensated current.

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With the change in the shape of the welded parts, there is also a change in the design of certain tools in a dot-welding machine, for example, the electrode

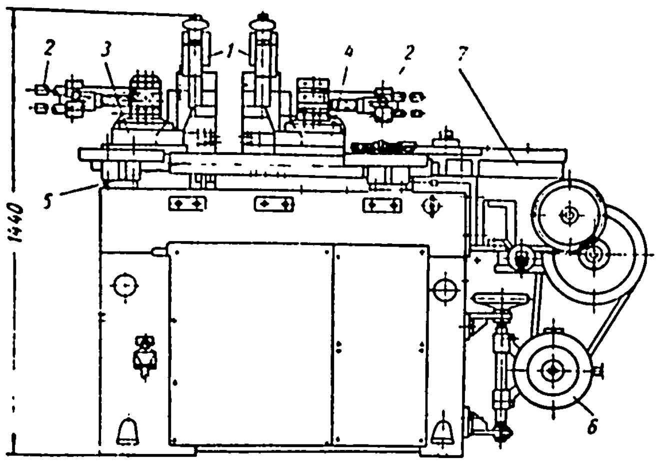

Fig.6 - Automatic Butt-Welding Machine Type MSM-150

1 - Pnuematic squeezers; 2 - Adjustable props; 3 - Stationary plate; 4 - Movable plate; 5 - Guides; 6 - Drive; 7 - Box with upsetting cam

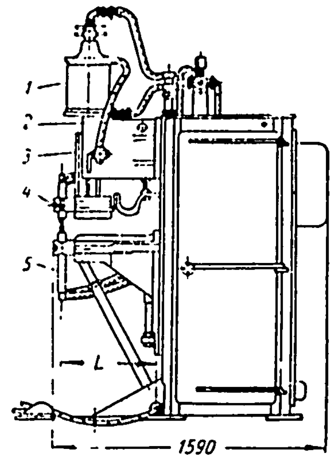

Fig.7 - Dot-Welding Machine Type MTP-75

1 - Pnuematic cylinder; 2 - Upper bracket with guides; 3 - Movable head; 4 - Upper shoulder of machine; 5 - Electrode holder (spark plug)

L - Machines effective clearance

holder (1) and electrodes (2), in Fig.8.

Welding Presses. Relief and T-shaped welding is performed by dot-welding machines or by welding presses with a power of 200 - 600 kv-amp (MRP-200-600). The presses differ from the dot-machines by having a smaller effective clearance, flat contact plates and requiring a larger compressing force (5500 kg in

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press MRP-600).

Roller-Welding Machines. Basic specifications for roller-welding machines are shown in Fig.9.

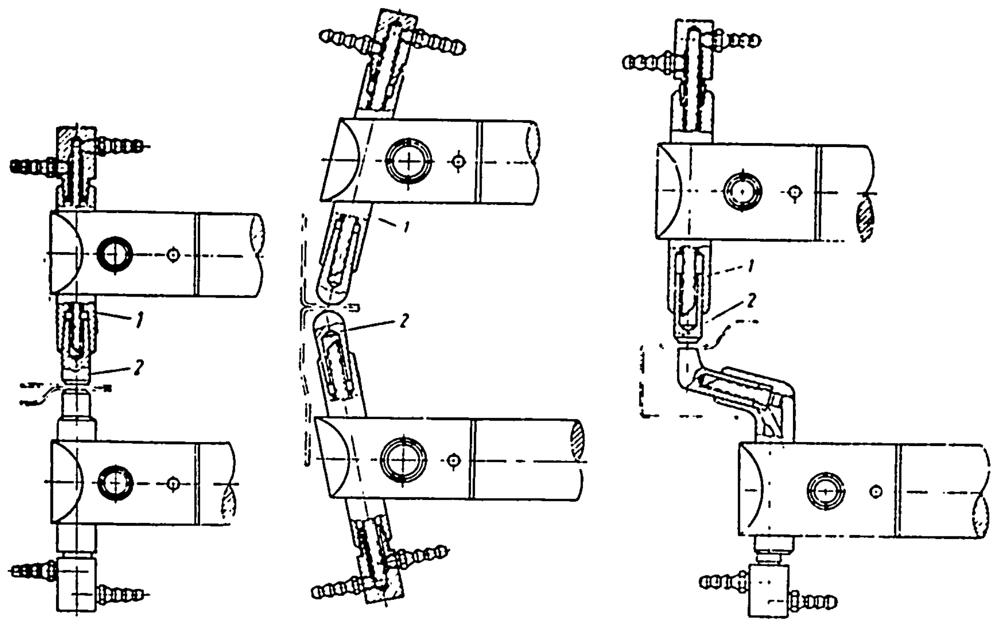

Fig.8 - Operating Tools of Spot-Welding Machines

Parts designed for severe operating conditions are welded by MShP machines equipped with ignitron interrupters designed for the welding of transverse and longitudinal seams (the electrodes rotate 90° around their vertical axis).

Machines with a power of 70 - 200 kv-amp and with a welding speed up to 30 m/min are used for butt-roller welding of tubes having a diameter up to 70 mm and a thickness up to 3 mm.

Contact Welding Technology

Butt Welding. In industry, butt welding by melting is used to a much greater extent than resistance welding and it is due to the fact that butt welding by

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melting produces much better joints.

Table 8

Basic Specifications of Spot-Welding Machines

Specifications	Machine Types				
	ATP-10	ATP-50	MTM-50	MTP-75	MTP-200
Primary voltage, in v	220; 380	220; 380	220;380;500	380	380
Rated power, in kv-amp	10	50	50	75	200
Rated PV, in %	[illegible]5	12.5	12.5	20	20
Control limits of the secondary voltage in v	1.6-2.6	2.9-5	2.9-5.0	3.4-6	4.7-8.4
Machine operating principle	Nonautomatic		Automatic, also suitable for nonautomatic work		
Drive of pressing mechanism	Pedal		Electric	Pneumatic	
Movement of upper electrode	Along a circuit arc			Vertical	
Maximum force developed on the electrodes, in kg	110	250	250	550	1500
Method of turning on and off	Pedal		Cam	Electron time regulator	
Type of switch	Mechanical			Magnetic contactor or ignitron	Ignitron asynchronous
Welding current at rated power in amp	6000	11,500	10,000	14,000	25,000
Maximum number of weldings per hr in automatic welding	-	-	3000	4000	3600
Ditto in nonautomatic welding	1000	800	800	1000	600
Duration, in second of current turned on during automatic welding of one dot	-	-	0.2-0.35	0.04-6.5	0.04-6.5
Maximum thickness of welded part in automatic welding of low-carbon steel, in mm	1	-	2 + 2	2.5 + 2.5	6 + 6
Ditto, in nonautomatic welding of moderate quantities, in mm	1.5 + 1.5	3 + 3	3 + 3	3.5 + 3.5	7 + 7

Conditions resulting in a good welding are: a correct rise in temperature until a film of molten metal appears and a complete removal of this metal after the upsetting. The factors determining the quality of the welding process by melting are as follows:

a) The length l of the portion let out from the electrodes, the amount of which helps or hinders the rate of heating. In the welding of steel parts having a diameter d; the length should be set to equal $l = (0.7 - 1)d$.

b) The amount of metal allowed as extra and by the rate of melting. Both of these (if there was no preliminary heating) will affect the rate of heating the welded parts. The melting usually takes place over a length of 6 – 20 mm and proceeds with a speed of 1 – 3 mm/sec. When the parts are preheated (800 – 1000°C) the allowance of extra metal may be reduced by 30 – 50%. In welding steels containing relatively large amounts of chrome (stainless steel) or silicon (transformer steel) the rate of melting should be increased to avoid oxidation in the welding zone.

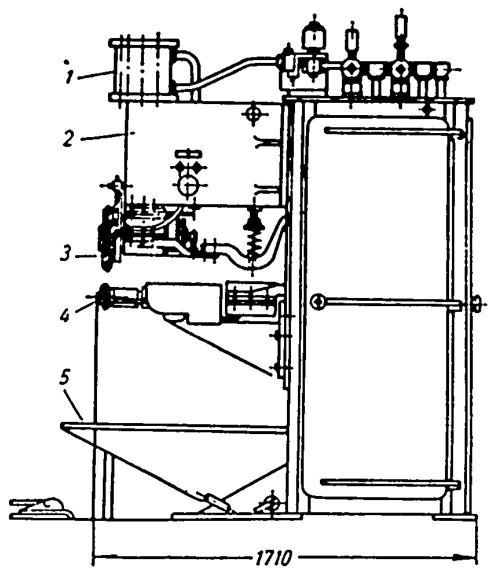

Fig.9 – Roller-Welding Machine MSHP-100-1

1 – Pneumatic cylinder; 2 – Bracket with guides; 3 – Upper electrode (unmovable); 4 – Lower movable electrode; 5 – A dish for water, if the electrodes are cooled externally

c) The specific power (q = kv-amp/mm^2) which becomes larger as the rate of melting increases and or the duration of the melting decreases. In mass production using the continuous melting process of welding, the q should be made to equal 0.15 – 0.40 kv-amp/mm^2, if the parts are not preheated; under the same conditions, but with a preheat, q = 0.12 – 0.16 kv-amp/mm^2. In the welding of small quantities with a preheat, q should equal 0.05 – 0.08 kv-amp/mm^2. In the welding of ring-shaped parts, q should be increased by 40 – 60%.

d) The combined conditions in the upsetting of the welded portions of the metal, i.e., the shortening of the Δ_{os}, the speed v_{os} and the specific pressure p measured in kg/mm^2. In practice, Δ_{os} = 3-8 mm, v_{os} = 15-30 mm, with a larger speed required for the welding of alloyed steels; as to the specific pressure, it should be set to 5-7 kg/mm^2 in the welding by continuous melting of low carbon steel,

Table 9

Basic Specifications for Roller-Welding Machines

Specifications	Machine Types		
	ASShP-25	MShP-100-1*	MShP-100-3
Primary voltage, in v	220, 380	380	380
Rated power, in kv-amp	25	100	100
Rated PV, in %	[illegible]-4.5	3.3-6.7	3.3-6.7
Control limits of secondary voltage in v	[illegible]-4.5	3.3-6.7	3.3-6.7
Drive of compressing mechanism	Pedal	Pneumatic	
Movement of upper electrode	Along a circular arc	Vertically	
Maximum power developed in electrodes, in kg	250	800	800
Effective clearance, in mm	400	800**	800**
Operating movement of electrodes, in mm	[illegible]	55	40
Type of switch	Mechanical	Synchronous ignitron interrupter with electronic synchronizer	
Direction of welded seams	Longitude or transverse	Transverse	Longitudinally
Welding speed, in m/mn	0.8-4.7	0.8-3.5	0.8-3.5
Speed control	In stages	Not in stages	
Possible current at the rated power, in a	[illegible]	17,000	17,000
Maximum thickness of low-carbon steel with the welding speed at minimum, in mm	1 + 1	1.5 + 1.5	1.5 + 1.5

* Similar machine types MShP-150-1, MShP-2, MShP-3, MShP-4 differ in transformer power

** In machines MShP-100-2 and MShP-100-4 the effective clearance is 550 mm

to 7-14 kg/mm^2 in the welding of alloys of the perlite group, and to $p = 15$-20 kg/mm^2 in the welding of austenite steels. When the parts are preheated, (which eases the plastic deformation) p may be decreased by 25-40%.

e) The duration of the process (t_{sv}) which depends on the cross section and the material to be welded, and also on the power of the equipment used. In practice, $t_{sv} = 5 - 40$ sec, however, for parts with a cross section of 5000 - 20,000 mm^2 t_{sv} may reach 3 - 8 min.

Dot-Welding. The cross section of a welding dot consists of a lentil-shaped nucleus having a rod-like structure typical in castings, surrounded by large-grained metal in the zone of overheat, after which (in the case of steel of the perlite class) follows the zone of small normalized grains merging with the metal to be welded.

The nucleus diameter (d_m) which determines the strength of the dot depends on the heating conditions, i.e., on the technological process. Under normal conditions, $d_m = 2 \; + 3$ m, where δ is the thickness of the thinest of the welded parts in mm; and $d_e \approx d_m$, where d_e is the diameter of the contacted surface of the electrode.

Conditions required for dot welding are described in Table 10, the conditions being for the dot welding of low carbon steel, which, together with austenite stainless steels, is best for dot welding. To improve the plasticity of the dots (if the steel is to be tempered), it is advisable to have the electrothermal treatment performed in the machine, directly.

Of the copper alloys, silicon bronze is best for dot welding, and phosphoric bronze is not as good, brass L62 is satisfactory and copper dot welds badly. Aluminum dot welds satisfactorily.

Before the dot welding, steel must be clean and the rust and scale must be removed by etching, sanding, or by abrasives. Aluminum alloys having a film of Al_2O_3 are cleaned by etching or mechanically.

Relief Welding. The normal diameter of each projection is 3 - 5 mm, its height is 0.75 - 1.5 mm. The power required for each for the compression projection is dependent on the thickness of the stamped part. With $\delta = 1$ mm, $P = 100 - 200$ kg, with $\delta = 2.5$ mm, $P = 350 - 450$ kg. The welding quality is just as good, as the precision with which the parts and their projections are stamped.

Roller Welding. The quality of the seam and its stability, the welding without damaging the welded surface and without wearing out the electrodes, all these

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are made possible by the interruptions in the welding current.

The ratio $\frac{t_{sv}}{t_{sv} + l_n}$ is usually within the limits 0.5 - 0.7 for low carbon steels; 0.4 - 0.6 for austenite stainless steels and 0.16 - 0.33 for aluminum alloys. t_{sv} is the duration of one impulse of the welding current, t_n is the duration of the pause between consecutive impulses.

Table 10

Desirable Conditions for Two-Sided, One-Dot Automatic Welding of Low Carbon Steel

Thickness of Each Part in mm	Electrode Contacted Surface Diameter in mm	Duration of Flow of Welding Current in sec *	Force Applied to Electrodes in kg **	Welding Current in amp
0.5	5 - 6	0.2 - 0.3	30 - 40	4000 - 5000
1	5 - 6	0.2 - 0.35	80 - 120	6000 - 7000
1.5	6 - 7	0.2 - 0.35	1[illegible]-160	7000 - 8000
2	8 - 10	0.25 - 0.35	150 - 250	9000 - 1[illegible],000
3	10 - 12	0.6 - 1	500 - 600	12,000 - 16,000
4	12 - 14	0.8 - 1.1	600 - 800	14,000 - 18,000
5	12 - 14	0.9 - 1.4	700 - 900	17,000 - 22,000

* The duration of a full welding cycle of one dot depends on the machine type

** In welding low-alloyed steels, the compression force should be increased 40 - 50%

Operating conditions for the roller welding of low carbon steels are described in Table 11.

<u>Electrode Materials</u>. The material from which electrodes are to be made for contact-welding machines should posses the following qualities: a) high electric and heat conductivity; b) good hardness; c) high recrystallization temperature; d) low tendency to form alloys with the welded metal. In use are copper electrodes, pure or with an admixture of chrome and zinc (alloy EV) or cadmium (up to 1%) and also multialloyed electrodes (Mts-4).

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GAS-FLAME TREATMENT OF METALS

Sources of Gas and Flame

Gas-Flame Treatment of Metals (Russian abbreviation: G.O.M.) is a combination of processes in which the shape and properties of the product metal is obtained by

Table 11

Desirable Conditions for Roller Welding of Low Carbon Steels with Strong and Solid Seams

Thickness of each Part in mm	Electrode Dimensions in mm		Force Applied to the electrodes in kg	Welding Speed, m/min	Welding Current, amp	Duration, in sec	
	Width of Operating Part	Desirable Diameter				Welding Impulse	Pauses
0.25	3.5-4	150-180	80-120	2.5-3.5	4000-6000	0.03-0.05	0.01-0.02
0.5	4.5-5	150-180	150-200	1-3	5000-8000	0.04-0.08	0.02-0.04
1	6-7	180-220	180-300	1-3.5	6000-15,000	0.04-0.08	0.02-0.04
1.5	7-8	220-250	250-375	0.6-1.5	10,000-18,000	0.08-0.16	0.04-0.08
2	8-9	240-260	320-450	0.5-1	18,000-30,000	0.14-0.24	0.08-0.12

heating locally with a gas flame. The gas-flame method may be applied in welding, melting, soldering, in cutting through, in surface cutting, in the tempering of the surface, in metallization, in bending, etc. The gas-flame treatment of metals requires an intensive heating of portions of metal with results depending on the thermal efficiency of process η.

$$\eta = 1 - \frac{t_k}{t_g}$$

where t_n is the required heating temperature; t_g is the temperature of the flame. To raise t_g and η, the combustible gases or vapors combine with oxygen.

Oxygen. In a gaseous state, one m^3 of oxygen, at 0°C and under a pressure

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of 760 mm Hg weighs 1.423 kg, and at 20°C - it weighs 1.312 kg. One m3 of oxygen gas is equal to 1.265 liters of liquid oxygen, which at atmospheric pressure will boil at a temperature of -183°C. One liter of liquid oxygen weighs 1.13 kg and, when vaporized, will produce 790 liters of gas. Oxygen is delivered under pressure in balloons (GOST 949-41) or in liquid form in tanks, wherein the oxygen is isolated from the surrounding medium.

Most widely used are balloons with an capacity of 40 liters containing 6 m^3 of oxygen under a pressure of 150 atm (gage). The balloon valve is made in accordance with GOST 699-53.

Oxygen in balloons is very convenient, but on account of the balloon weight, cost too much in transportation charges.

Liquid oxygen is utilized by means of a gasifier which acts as a central feeding point. At present, mostly used are cold gasifiers in the form of spherical vessels protected by a heat-isolating jacket. Such a gasifier contains 1000 liters of liquid oxygen or 800 m^3 of gas. From the gasifiers the oxygen is delivered under a pressure up to 15 atm (gage) at the rate of 100 m3 per hour.

Combustible Gases. Gases and vapors producing, when combined with oxygen, a high temperature flame, are very important in the gas-flame treatment of metals. Best results are produced by combustible materials containing a high percentage of carbon.

Table 12 shows the characteristics of certain combustible gases.

The highest flame temperature is produced by acetylene. In many cases, however, it may be substituted by other combustibles. Excepting copper, the welding of metals may be effected by benzene, propane, butane, hydrogen, petroleum gases, manufactured gases and natural gases.

All of the combustibles shown in Table 12 may be used with oxygen for soldering and for cutting.

For a preparatory flame, the amount of oxygen (in cutting) equals to 80-85%

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Table 12

Characteristics of Combustible Gases

Name of Combustibles	Specific Weight, kg/m^3	Heat Capacity (Low value)		Temperature of Welding Flame, in 0°C	Amount of Oxygen per One m^3 of Combustibles, in m	
		In cal/m^3	In cal/kg		For Full Combustion	For Welding
Acetylene	1.17	13,500	11,500	3100	2.5	1-1.1
Hydrogen	0.09	2570	28,800	2100	0.5	0.25
Propane	2	22,100	11,000	2050	5	2-2.5
Butane	2.7	29,500	11,000	2050	6.5	2.5-3
Natural gas	0.75	8300	9700	1000	2	1
Coke-oven gases	0.45-0.6	3800-4500	7500-8800	2000	1	0.6
Petroleum gases	0.7-1.5	10,500-14,500	9500-16,000	2100-2300	2-2.5	1
City gases	0.8-1.1	3200-6500	4000-6000	1900	1.2-1.6	0.6-0.8
Gasoline, Kerosene	0.7-0.8*	-	10,000	2300	2.4**	1.3-1.5**

* In kg/ltr ** In m^3/kg

Table 13

Specifications of Gas Producers

Capacity m^3/hr	Trademark	Pressure, in atm (gage)		Type	Weight of Metallic Parts, in kg	Kind of Work
		Operating	Maximum			
0.8	GVD-0.8	[illegible]	1.5	Portable	16	Repairs
1.25	GVD-1.25	0.02	0.07	"	42	Single operator
1.25	GVD-1.25	[illegible]	[illegible]	"	50	" "
2[illegible]	MG-55	0.03	0.08	Movable	65	" "
3	GVR-3	[illegible]	[illegible]	Stationary	110	Single and multioperator
10	GRK-10	[illegible] 0.7	1.5	"	650	Multioperator
35	GND-35	0.12	1.02	"	4 5 m	For acetylene stations

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of the amount required for full combustion.

All of the combustible gases, when mixed with air or oxygen, are explosives. The safety of operations is insured only by the strict compliance with the rules to be worked out by the management.

Acetylene is a colorless gas with a specific weight 1.179 kg/m^3. In large volumes and under a pressure of over 2 atm (gage), acetylene, when heated or struck, may explode. Acetylene forms explosive mixtures when from 2.8 to 65% of it is contained by air, and when 2.8 to 93% of it is contained in oxygen.

Acetylene is produced by water acting on calcium carbide. Taking into consideration the losses, one kg of calcium carbide will produce 0.25 m^3 of acetylene.

Acetylene is produced by acetylene generators with capacities, pressures, dimensions and types specified by GOST 5190-49.

Inasmuch as pressure is concerned, there are low-pressure generators with a limit of 0.1 kg/cm^2 and medium-pressure from 0.1 to 1.5 kg/cm^2.

The welding data for the generator are shown in Table 13.

The manufacturing of the gas-producers is governed by the chief oxygen producing organization MKhP (GOST 5190-49).

Acetylene may be delivered in balloons (GOST 5948-51). Under a pressure of 16 atm (gage) acetylene dissolves in acetone which saturates the pores of the vessel. A vessel of 40 liters capacity contains 4-5 m^3 of acetylene.

Acetylene vessels are filled by special units at the rate of 5, 7 and 35 m^3/hr.

Acetylene may be delivered by a pipeline, at any rate, before the place of consumption, safety valves are installed for low-or medium-pressure acetylene.

Equipment for Distribution. For distribution to consuming points, the vessels containing acetylene are placed on acetylene, oxygen or other ramps. To reduce and regulate the pressure there are reducers specified by GOST 6268-52. Specifications of these reducers are shown in Table 14.

To bring the gas to the machines, a rubber hose specified as GOST 71-55 is made with a diameter of 9.5 mm.

The Acetylene Flame. The physical and chemical conditions for gas-flame treatment of metals allow an incomplete combustion of acetylene in the heating zone. The reaction is as follows:

$$C_2H_2 + O_2 = 2\ CO + H_2$$

A flame of such composition is called normal. It has a clearly outlined cone

Table 14

Specifications for Reducers

Trademark	Gas	Maximum Operating Pressure in atm (gage)	Maximum Delivering Capacity m^3/hr
RK-53	Oxygen	15	60
KRR-50	"	25	200
RA	Acetylene	1.5	4

or taper. Characteristics of such flames are shown in Table 15.

Characteristics of other flames are similar to oxy-acetylene flames.

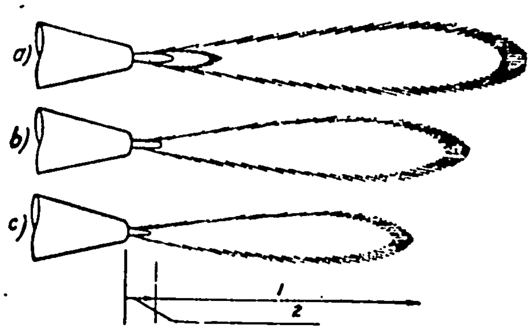

Fig.10 - Oxy-Acetylene Flame

1 - Flame torch; 2 - Flame taper

Gas Welding

The application of gas welding is made practical because of: a) its universality, i.e., it offers a possibility to perform various operations with the use of a single unit of simple design; b) its advantages in welding of nonferrous metals and cast iron; c) the flexibility of the process and its convenience when welding thin sheets and pipes, d) good formation of the seam; e) the possibility of combining thermal and mechanical treatment.

Table 15

Characteristics of Oxy-Acetylene Flame

Flame	Ratio $O_2:C_2H_2$	Temperature in $^{\circ}C$	Field of Application
Carbonizing (Fig.10a)	0.8 - 1	2700 - 3100	Depositing hard alloys. Welds high carbon steels
Normal (Fig.10b)	1 - 1.2	3100	Welding, cutting, soldering, metalizing
Oxidizing (Fig.10c)	1.2 - 1.5	3100 - 3300	Cutting and soldering, welding brass, cast iron with bronze. Tempering, fire cleaning of surface

Gas welding is used in the aviation industry, in building of energy-producing machinery, in the manufacture of chemical equipment, in the production of pipes and tubes, for mechanical repairs, in foundries, in tractor stations and for field work.

The Welder Burner combines in itself the heating element and the means to produce a seam.

Characteristics of welding burners are described in Table 16.

The Gas-Welding Technique. In gas-welding, the flame serves to melt the metal locally. In addition, the flow of gas exerts a pressure which shapes the molten metal into a seam. The gas flame melts a segment whose width is 2.5 - 3 times the depth. Melting down a depth greater than 5 - 6 mm is difficult due to the excess of liquid metal. When welding thick parts, therefore, the seam is prepared by beveling the edges producing thereby an opening for heating along the entire cross section. The shape of the seam and basic preparatory methods are described in Table 17.

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After preparing the edges, the parts are assembled for welding, with care being taken to maintain the required clearance d along the entire line. The dulling

Table 16

Characteristics of Welding Torches

Items	Torch Tips by Number							
	0	1	2	3	4	5	6	7
Welding torches, normal GS-53	-	(+)	(+)	+	+	+	+	(+)
Welding torches, small GSM-53	+	+	+	+	(+)	-	-	-
Average consumption of acetylene, liters/hr	40	80	180	320	550	900	1400	2400

of the edges by an amount h should not be overlooked. This is necessary to prevent the edges from overburning. Before the welding starts, the edges are to be tightened in the required position. Ordinarily, grippers serve the purpose. In mass-

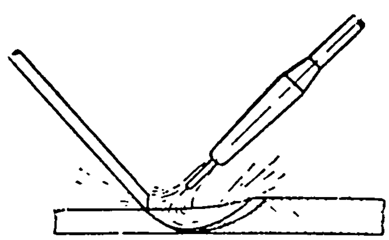

Fig.11 - Position of Torch during the Welding

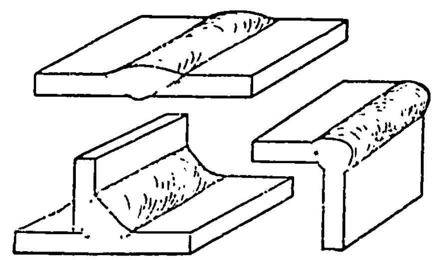

Fig.12 - A Sketch of Normal Gas-Welded Seams

production it is effected by mechanical devices.

Next comes the continuous heating of the metal by the flame of the torch, and to complete the welding, the welding rod is held in the zone of heating (Fig.11).

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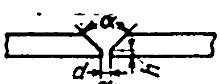
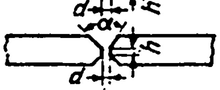
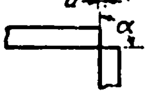
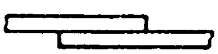
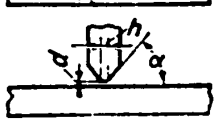
During the welding, the molten metal forms a welding bath driven into the space between the edges by the pressure of the gas and by the welding rod.

Table 17

The Shape of Seams and Basic Dimensions when Preparing the Edges for Welding

Sketch of Welding Method	Nature of Joint and Prepared Edges	Thickness of Welded Material, in mm	Dimensions, in mm and Angles, in Degrees		
			h in mm	d in mm	α°
	Butt joint, edges bent	Do 1.5	2	0-1	-
	Butt joint, edges not beveled	1-5	-	1-1.5	-
	Butt joint, only one side beveled	6-15	1-2	1.5-3	60-90
	Butt joint, both edges beveled	15	2-4	3-5	60-90
	Angular joint	-	-	-	60-120
	Overlapping joint	-	-	-	-
	Shaped joint, edges not beveled	Do 8	-	1-2	-
	Shaped joint, one side beveled	8-12	2-3	1.5-2	50-60
	Shaped joint, both sides beveled	12	2-4	2-4	50-60

The lower position of the seam welds best and takes less time to weld. However, fairly good quality welding of steel and of many others metals and alloys may be attained by welding vertically or overhead.

A well-done welding seam (Fig.12) is one welded along the entire cross section with a streamline adherence of the edges (of the deposited metal) to the welded metal and with the middle part of the seam made stronger.

The Welding Ability of Metals. Low-Carbon Steels weld good, if the carbon content does not exceed 0.20%, and satisfactorily, if the carbon content does not exceed 0.35%. Low-carbon steels are also weldable in all positions.

Table 18

Mechanical Properties of Deposited Metal in Welding

Properties	Sv-08 Sv-08A Sv-15	Sv-08G Sv-08GA Sv-10G2 Sv-15G	Sv-10GS
Yield point, in kg/mm^2	17-25	20-30	-
Tensile strength, kg/mm^2	33-36	33-44	43-48
Elongation, %	8-16	8-16	8-16
Viscosity factor in original state, kgm/cm^2	1-4	4-10	5-7
Ditto after normalization in kgm/cm^2	4-14	8-14	9-14

The wire for the welding rod is specified by GOST 2246-54 and embrace types Sv-08, Sv-08A, Sv-08G, SV-08GA, Sv-10G2, Sv-15, Sv-15G, Sv-10GS.

The mechanical properties of the metal deposited during the welding are shown in Table 18.

The normalization is performed by a repeat heating of the welded seam by means of the welding torch which brings the temperature to 930-950°C.

A certain additional strength may be imparted to the seam by forging it in the hot state, with the normalization to follow.

As a rule, Low-Alloyed Structural Steels are just as weldable as low-carbon steels.

In the welding of alloyed steels, the largest factor affecting the welding ability is the amount of carbon present, as shown below:

Carbon Content in %	How the Welding Ability is affected
up to 0.2	Good welding ability is maintained
0.2 - 0.3	Welds satisfactorily with slightly carbonizing flame and with alloyed metal as a welding rod
0.3 - 0.4	Welding ability limited with conditions as above and with a preheat.
over 0.4	Welds badly, allows metal depositing with a carbonizing flame.

Heat-treated steels of the perlite group weld fairly well, if the carbon content does not exceed 0.3 - 0.35%. Cracks in the zone of the seam, which may appear as a result of tempering, may be avoided by heating the seam to 150 - 250°C. Martensite steels belong to the group with poor welding abilities. Welding of these steels may be effected by heating to 400 - 500°C. Austenite steel with a low carbon content welds well. Carbide instrument steel may be welded only when small in volume, but it is good for metal depositing.

Table 19

Composition of Fluxes, in %

Welded Metal	Borax Decahydrate	Borax Dehydrated	Silicious Earth	Other Additives
Stainless steel	-	67	32.6	Ferrochrome 0.15 Ferromanganese 0.25
Cast iron	100	-	-	
	50	-	3	Sodium bicarbonate 47
Copper, brass, bronze	-	70	-	Boric acid 10 Sodium chloride 20

Other elements serving as alloys affect the welding ability as follows:

If the alloy and carbon content is not high, namely (in %): Mn $<$ 1-1.5, Si $<$ 0.8, Ni $<$ 3, Cr $<$ 1, Mo $<$ 0.6, V $<$ 0.3, W $<$ 0.5, Cu $<$ 0.6, Ti $<$ 0.3 - they

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will either help, or will not hinder the welding.

When welded in large quantities, medium and high-alloyed steels, once the carbon content exceeds 0.25%, develop a tendency to become tempered and develop cracks. Especially Mn, Cr, Ni, Mo, and W develop this tendency.

Some of the elements (Si, Cr, V, W, Al) if contained in larger quantities form hard to melt oxides which hinder the welding and lower the plasticity of the molten metal.

In the welding of alloyed steels are used fluxes (see Table 19) and welding rods sepcified by GOST 2246-54.

Grey Iron is suitable for a good quality welding by gas with a normal flame.

A uniform heating of the segments to be welded and the use of welding rods specified by GOST 2671-44, also the use of a flux with a composition shown in Table 19, will make the deposited metal easy for treatment.

To avoid cracks during the welding of parts having a complex shape, the parts are subjected to a common (in toto) heating followed by a slow cooling in the furnace after the welding. The heating should be at a temperature of 450 - 550°C; instead of cooling in the furnace, it may be done under a cover possessing good isolating properties. Parts of simple shapes are welded without the common heating.

The welding of cast iron by welding brass produces good results, and in many cases, no heating is required. The welding rod contains 60 - 63% of Cu, 0.4 - 0.6% of Sn,).3 - 0.4% of Si, the remainder being zinc.

The surface area covering the cast iron and the deposited metal must exceed the cross section of the seam by 2 - 2.5 times. In using the flux, the edge surfaces are served first and the filling of the seam is done after. The welding is effected by an oxidizing flame ($O_2:C_2H_2 \approx 1.35$).

Copper of grades M1 and M2 weld well. Copper of grade M3 and M4 containing copper oxides will, when welded, produce a brittle zone alongside the seam.

The high heat conductivity of copper demands an intensive flame. Wires made

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from electrolytic copper are recommended for the welding rods. Fluxes are also used (Table 19).

The welding of copper should be rapid. Hot forging of the welding seam is recommended. The welding should be done without overheating which causes oxidation and makes the deposited metal brittle. An excess of combustible gases and water vapors mixed with the gas have a damaging effect during the welding because copper, and all of its alloys, absorb hydrogen resulting in pores. The seam, if well welded, has properties equal to the properties of the welded metal.

Brass welds well, especially if the zinc content is high (about 40%). The deposited metal contains 60 - 63% copper, 0.3 - 0.4 Si and the remainder is zinc.

The welding is performed by an oxidizing flame (O_2: $C_2H_2 \approx 1.35$) and flux is used for the copper.

Bronze containing up to 7% of tin welds well. With a greater tin content, a preheat before the welding is required with a gradual cooling to follow.

Silicon and Manganese bronzes belong to the good-welding alloys and their welding seams posses high mechanical properties.

Aluminum and Ferroaluminum bronzes weld satisfactorily with the aid of active fluxes.

Aluminum welds well. There is always on the surface a hard to melt film of aluminum oxide which cannot be reduced by the flame. For this reason a flux is necessary, the composition of which should be made of: sodium chloride 30%, potassium chloride 45%, lithium chloride 15%, potassium fluoride 7%, potassium oxide and potassium sulfate 3%.

The mechanical properties of the deposited metal are the same as of the welded material. A thorough cleaning after the welding is necessary to remove the flux, the remnants of which will quickly corrode the seams.

Silimin castings are welded with a preheat of 200 - 300°C.

Magnesium welds satisfactorily with the aid of fluxes to protect if from oxi-

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dation.

Lead welds well but requires special equipment of low power and a qualified welder.

Technological Indexes in Gas Welding. The heat quantity Q spent per unit of length of the seam i, which logically, is the amount of combustibles W is directly proportional to the weight P of the molten metal. Therefore, $Q = kW = k_1P$, where k and k_1 are coefficients of proportionality.

In most of the welded joints:

$$P = k_2\delta^2 \text{ kg/m}$$

where δ is the thickness of welded parts.

The quantity of heat may be expressed as

$$Q = \frac{Q}{t} t = k_3\delta^2$$

in this equation $\frac{Q}{t}$ is the calories/hour and t is the welding time, in hours.

In practice, it may be reasonable to assume that

$$\frac{Q}{t} = k_4\delta \text{ and } t = d\delta$$

The power of the welding flame M is the consumption of gas per hour, i.e.

$$M = \frac{W}{t} = c\delta \text{ gas/hr}$$

The value of c in welding parts with a thickness of 1 – 15 mm are shown in Table 20.

Welding Time. Technically, the welding time (basic and auxiliary) for low-carbon steel is expressed as $t = d\delta$ min/m. The following values for the coefficient d are recommended:

Metal	d
Low-carbon steel	5 – 4

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Metal	d
Alloyed steel, cast iron, copper alloys	6
Copper	3.5
Aluminum	4

Consumption of Materials per 1 m of Seam in Average Welding Conditions

Acetylene	$8\delta^2$ liters
Oxygen	$9.5\,\delta^2$ liters
Welding wire, edges beveled 45°	$10\,\delta^2$ gr

In welding of voluminous parts, where the length of the seam is not taken into account, calculations are made by volume and weight.

In the average, one m^3 of acetylene will melt 1 kg of steel. Correspondingly, the quantity of acetylene required will be $W_a = P$, for oxygen $W_k = 1.15\ W_a$.

In selecting a torch with a power to fit the thickness of the welded material,

Table 20

The Value of Coefficient c

Joint	Low-Carbon Steel	Alloyed Steel Cast Iron	Copper	Copper Alloy	Aluminum
Butt	100	80	130-180	75-85	110-130
Overlap	140	110	180-250	100-110	150-180
Shaped	150	120	200-300	100-120	160-200
Angular	80	70	110-150	70-80	100-120

the welding time is found as follows:

$$t = W_a : \frac{W}{t}$$

Automatic Gas Welding. The automization of gas welding is most widely used in the welding of thin-walled pipes. Machines for this purpose shape the pipe from a strip, welds it with a longitudinal seam, trues the pipe and cuts it into required lengths. The welding speed reaches 500-2000 m/hr with a high quality welding seam. Automatic welding by gas of alloyed steels (stainless steel, for example) is also possible. There are automatic machines for gas-welding shells, for gas-welding bottoms to vessels, etc.

Gas Welding Under Pressure

In gas welding under pressure, the welded joint is the result of pressure applied to parts of the material heated by an oxyacetylene flame until a weldable temperature is reached, at this, the heated part may be in a solid or molten state. In the welding of low carbon steels, the temperature, for example, reaches 1200°C, and the pressure may reach 250 - 400 kg/cm^2. Gas welding under pressure is performed by machines, consisting essentially of a squeezing device, welding press and a torch for heating. The automatic units contain, in addition, a drive, an acetylene producer, a ramp for oxygen tanks, transporting devices, etc.

These units are applied in pipe welding and in the welding of parts having solid cross sections.

The unit VNII made by Autogen MGPS 15/160-53 is fully automized and is used for welding pipes 30 - 160 mm in diameter and parts with a cross-sectional area up to 80 cm^2 with a compression force up to 15 m.

Belonging to the same type are TsNII, MPS, SGP2 and SGP-7 units. Of the less powerful units are SGP-3 and SGP-30 with a power of compression in the order of 2 - 4 m.

The burners, or torches, used for heating are so designed that their flame embraces the part along its entire contour. The burner KG is designed for pipes 30 to 630 mm in diameter.

Technically, the gas welding under pressure units are similar to the butt-welding electrical machines, but possess the following advantages: a) a source of

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electrical energy is not needed, b) the oxyacetylene unit, weighing comparatively little, develops a comparatively large power, c) the simplicity of the process and of maintenance, d) the simplicity of the squeezing device requiring no electric energy and requiring no cleaning of the surface.

In gas welding under pressure with heating the parts externally, the parts to be butt-welded are carefully set in place, have their position carefully checked, then subjecting them to pressure and to heat until the required temperature is reached.

Normally, as a result of pressure, the welded seam is uniformly thickened. Partial melting of the surface may take place.

The selectior of welding burners for a required capacity should be based on the fact that acetylene is consumed at the rate of 2 liters per hour for each 1 mm^2 of the cross-sectional area of the welded joint. In the average, it takes 7-8 liters of acetylene to handle 1 cm^2 of the joint area. The time element is based on the figure of 10 sec per each 1 mm of the heated metal thickness.

In the gas welding under pressure when heating of the butt ends is required, the procedure is as follows: a flat burner with a flame on each of its two sides is introduced into the clearance between the two parts. As soon as melting starts, the burner is removed, the parts are made to touch each other and are pressed together.

Oxygen Cutting

Oxygen cutting is based on the property of iron to burn in oxygen with the emission of large quantities of heat and with the formation of molten iron oxides.

The burning of iron (steel) during the cutting takes place at surface where it meets the stream of oxygen. A preliminary intensive heating at the beginning and maintaining a high temperature is necessary to start the burning. For this reason, oxygen cutters consist of a gas-oxygen burner to which a tube for the cut-

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ting oxygen is connected.

In cutting, the purity of the oxygen is important. Best results are attained with oxygen 99.3 - 99.5% pure. Lowering the purity by 1% will increase the consumption by 25 - 30%, will reduce the cutting speed by 15% and will lower the quality of the cut. Oxygen with a purity of less than 95% is not recommended for cutting.

Of the combustibles used in cutting, acetylene, coke-oven gas, illuminating gas and others are suitable. Liquid fuels such as kerosene, etc may also be used.

The process of cutting, with the oxygen stream bisecting the material, is a separating operation. The oxygen stream which cuts the steel should be narrow and long. A scattered stream will result in a distorted surface and will slow down the cutting. The heating flame should be concentrated. An excessively hot flame will melt the edges of the cut. The cutting movement should be uniform, if not, it will result in deep strokes, tearing of the edges, etc, which may require mechanical repairs. The cutting, when correctly performed, will produce an even, rectilineal edge (Fig.13b). In the cutting with medium speed, the passing oxygen stream will produce marks on the surface. These marks are not very deep, but the lower part of the edge will look, as if receded (Fig.13a). Straight marks (Fig.13c) indicate a slow rate of cutting, which is necessary only for shaped and precise cutting by machines.

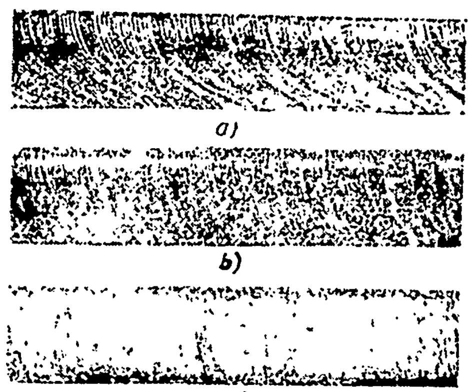

Fig.13 - Sketches of Oxygen of Good Quality

Oxygen cutting will not overheat or overburn the edge of the cut. The hot iron oxides melt and wash off the nonoxidized layer of metal and leave a clean metal surface. A surface layer with a depth of 2 - 5 mm is subjected to normalizing, or

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to tempering, if a tempered steel is to be cut.

The hardness, if too extreme, is remedied by local or by a general annealing. Cracks are possible when cutting tempered steels. These may be avoided by a preliminary heating of 100 - 200°C.

Table 21 shows the effect of certain alloyed steels on the cutting.

Table 21

Effect of Steel Alloys on Cutting

Degree of Influence	Content of Elements in % (Minimum)				
	C	Cr	Al	W	Mo
Makes it hard to cut	0.3	3	2	10	0.25
Hinders the cutting	0.8	6	10	20	-

The description of the separating type of cutters are given in Table 22.

In addition to these, there are cutters and cutting units to handle materials of comparatively large thickness (URR and PMR), for cutting chrome steels (URKhS), for underwater cutting (BUPR), for cutting with gases substituting for acetylene (RSZ and URZ) and others.

The Mechanization of the Separating Type of Cutting makes the stream of oxygen move in a more uniform manner thereby improving the quality and the productivity of the process. The mechanized equipment is subdivided into the following groups:

1) Equipment for manual cutting;

2) Devices for special operations;

3) Portable, self-propelling units;

4) Stationary machine.

The Equipment for Cutting Manually consists of a wheel-barrow to carry the cutters, guiding rulers, contour shapes, compasses, etc. All of these help to increase the precision of the cutting and help to steady the movements of the cutter.

Devices for Special Operations, as far as precision is concerned, are equal

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to machines. Among these are devices for straight cuts, for cutting-out circles, for cutting-off pipe pieces, for cutting-out shapes.

Of the Cutting Machines, there are portable and stationary units.

Most widely used are the portable self-propelling units which move over the surface of the material being cut, or the move is on special guiding rails.

Table 22

Specifications for Cutters

Type of Cutter	Field of Application	Thickness of Cut in mm	Remarks
RR-53	For manual cutting	5 - 300	Substitute for UR
AGS-53	For cutting in welding operations	Do 50	With burner GS-53
RGM-53	Ditto, for repair operations	Do 25	" " GSM-52
RMR	Used with cutting machines	5 - 100	
R-51	For cutting manually	5 - 200	For liquid fuel

The stationary machines are an example of perfection in the field of mechanization and of automation of the oxygen cutting process. These machines are able

Table 23

Cutting Machines Specifications

Type	Type of Machine	Area of Cut in mm	Number of Cutters	Thickness of Material	Purpose
PL-1	Portable	Unlimited	1	6 - 100	Cutting of material
PL-2	Portable	Ditto	2	6 - 100	Ditto, bevel edges
ASSh-2	Stationary, hinge type	750 × 1500	1	6 - 100	Cutting with high precision
ASP-1	Stationary, coordinate type	1500×(3000+9000)	1 - 3	6 - 200	Machine for general purposes
M-10	Stationary, parallelogram type	1000 × 3000	3 10	6 - 100	Mass cutting of same type of work

to perform straight and shaped cuts, and by means of certain mechanisms or ball joints are able to have the operating parts move longitudinally or transversely. The classification of this machine is in accordance with specifications GOST 5614-51.

Some of the data for commercial cutting machines are given in Table 23.

Machines of the hinge type (ASSh-1) are designed for precision cutting of complex shapes and are not designed for beveling edges of parts to be welded. Machines of the longitude-transverse type can handle a width of definite size (for example, ASP-1 can handle a width of 1500 mm) and any required length. These machines are equipped with one or several cutters for cutting several parts and for rectilineal cuts at an angle.

There are machines equipped with a photoelectronic device used for copying the cutting contour from a drawing, also machines for cutting sheets up to 2.5 m wide, machines with remote control and for copying-to-scale the required shape of cut.

The mechanical precision of the cut is determined by the type of machine design.

The deviation, when cutting with a precision-type machine, is $\pm$ 0.2 mm and, when using an average machine, it is $\pm$ 0.5 mm.

In cutting a sheet 25 mm in thickness, the deviation due to the inexact direction of the oxygen stream and to the burning of the metal will, in the case of a quality cut, be within the limits from $\pm$ 0.1 to $\pm$ 0.15 mm. The deviation will increase with the increase in the thickness of the material at a rate of 0.1 - 0.15 mm for each 50 mm of thickness.

In cutting large parts it is necessary to avoid deviations due to distortions caused by heat.

Such deviations may exceed the normal deviations expected from the machine. As a remedy, one of narrow sides of the material is fastened very tightly and the cutting, simultaneously from both sides (if possible), starts from the free end of the shape and is finished from the side where it is fastened.

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<u>Technological Indices in Cutting</u>. In cutting, the basis for calculations are the cutting speed and the amount of oxygen required to cut 1 cm^2 in cross section. The cutting speed may be linear cutting (augmented), in which the oxygen stream may be lagging, and shape cutting. These indices are represented by curves drawn in Fig.14.

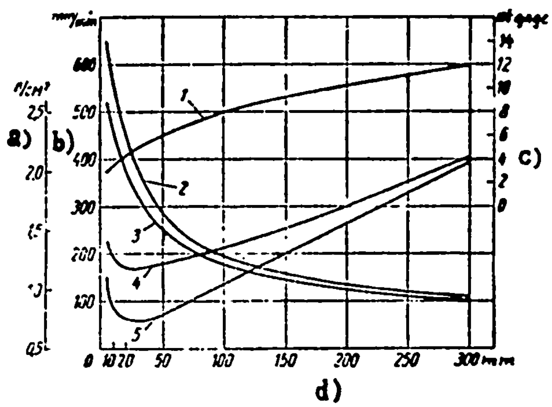

Fig.14 - Curves Showing Cutting Indices

1 - Oxygen pressure; 2 - Linear cutting speed by machine; 3 - Shape cutting speed (manual and by machine); 4 - Oxygen per 1 cm^2 in manual and machine shape cutting; 5 - Oxygen per 1 cm^2 in linear cutting by machine

a) Oxygen consumption; b) Cutting speed; c) Oxygen pressure; d) Thickness of metal

A certain type of equipment for cutting metals of large thickness (500-1500mm) operates with oxygen at a low pressure (1 - 3 atm).

Cutters using an oxygen stream inclined at an angle can cut steel sheets up to 20 - 25 mm thick at a rate two-three times the values shown in Fig.14.

When using other gases and operating with the same cutting speed as with acetylene, the duration of the initial heating is longer.

<u>Surface Cutting</u>. In the surface cutting, a wide soft stream of oxygen, directed to the surface at an angle of 20 - 30°, with an additional heating by an oxygen-gas flame forms a hearth, or a fireplace, which quickly moves away leaving a fluted dent.

For surface cutting special cutters, heads, and nozzles are used. The nozzles are widened to reduce the oxygen stream speed, if necessary. For the average type of work are used the RVP cutters which also repair defected welding seams and the RP cutters used to remove large defects from steel surfaces.

Manual surface cutting is done with a speed of 2 --6 m/min, leaving a groove 8 - 30 mm wide and 3 - 8 mm deep.

The oxygen consumption is approximately equal to 0.2 - 0.4 m^3 per each 1 kg of low-carbon steel removed.

Surface cutting is easily mechanized.

There are machines for surface cleaning of hot and cold-rolled steel. The machines used for cleaning of hot rolled steel are fully mechanized and are installed in the line of continuously operating rolling machines and blooming rolls. The oxygen cutters in these machines burn up the defective surface layer along the entire perimeter to a depth of 1 - 3 mm while the metal moves with a speed of 25 - 50 m/min.

A machine (SKS) has been developed which can fire-plane flat surfaces. The operating stroke of this machine can reach a length up to 1500 mm.

Depositing Molten Alloys

Field of Application and Properties of Alloys used for Depositing. The depositing of molten alloys is used for:

1) To improve the properties, strength and ability to withstand wear in the places where the molten alloy is deposited.

2) To reduce the cost of the product, if only a portion of it should have the required properties.

3) To lengthen the usefulness of the product by repeated alloy depositing, or using the alloy to restore the initial properties of the product.

The materials used for depositing are subdivided into:

1) Hard materials, of the carbide-martensite type which retain their hardness after annealing and are treated by abrasives, these are: a) castings - stellites VK2 and VK3 and sormite; b) powdered - stalinit and vokar; c) synthetics.

2. Hard, carbide-martensite type, heat treated: a) castings - sormite; b) rods

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– high-speed steel, etc; c) synthetics.

3. Hard, perlite-martensite type of rods used for electrodes; as follows

Type of steel	SV-I SV-II	18Kh14A	35Kh14A	3KhV8	8KhGn	7Kh3
Type of electrode ...	TsN-250, TsN-350	NZh-2	NZh-3	TsSh-1	TsSh-3	TsSh-3

4. Wear-resistant, austenite type (Gadfield steel) – electrodes OMG.

5. Corrosion resistant – electrodes E50-Ya.

6. Heat resistant – electrodes E55-Zh.

Remarks: The word "synthetics" used above means materials obtained from tube-rods having a core made from ferroalloys and from electrodes coated with an alloy.

Additional information about these materials and their application is given in Vol.6, Chapter VII.

Types of Steel used for Products Subjected to Metal Depositing. For metal depositing on new products, the metal of the product is either carbon steel, low carbon steel, or low-alloyed steel. Cutting and stamping tools are usually made from carbon steels 35, 40, and 45. Steels with a high carbon content is not recommended for products requiring strength which would be better served by low-alloyed steels, such as 30G2, 45G2, 45Kh, etc.

The Technology of Alloy Depositing. The depositing of alloys is done more often by one of the following three methods:

1) Oxyacetylene flame;

2) Electric arc using a carbon electrode (Bernados method);

3) Electric arc using a metallic electrode (Slavianov method).

The first method produces a molten layer of uniform composition, the second and third methods are more economical.

The metal or tool to be restored, if very hard, must have the hardness reduced somewhat, or undergo annealing. Before the depositing operation, all cracks should be removed, and all deep cracks and grooves should be welded.

Cracks and other defects if left under the deposited metal will cause its de-

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struction.

The layer thickness produced by depositing hard carbide alloys should be within the limits of 0.5 - 2 mm. Thick layers are not advisable, due to the tendency to form cracks. Viscous or plastic materials may be deposited to any thickness. Figure 15 shows samples prepared for metal depositing. Figure 15a is for carbide alloys and Fig.15b is for special steel.

The technological conditions and methods should be such as to insure a thorough fusion of the deposited metal with the metal of the product without allowing them to mix. Also, to avoid formation of cracks and other defects in the deposited metal layer.

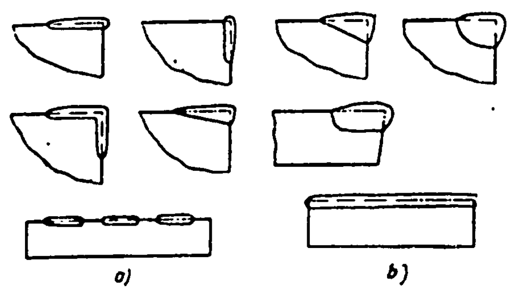

Fig.15 - Samples Prepared for Metal Depositing

Products to be deposited with hard alloys, or products made of steel which have a tendency to become tempered, as a rule, should be prelininarily heated to 350 - 500°C.

Such products should be slowly cooled after the alloy depositing is over. After the cooling, the deposited places are subjected to a mechanical treatment, if necessary. Carbide alloys are treated with abrasives.

Depending upon the condition of the product, the time spent in depositing of an alloy is 0.12 to 1.2 min/cm^2.

The depositing of hard alloys will lengthen the useful life of the product 3 - 4 times in the average and worn-out products may be restored many times.

Fire Cleaning of Metal Surfaces

This method is based on a rapid heating of the surface to a high temperature

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which will bring about the dissociation of the layers of rust, paint, etc. from the surface. The remnants are easily removed with a metal brush.

For this purpose there is an oxyacetylene burner GPZ having a flat multiflame tip 100 mm wide. This is an injector-type burner requiring a pressure for the acetylene of not less than 0.04 atm, consuming a 2 m^3/hr of acetylene and 2 - 2.5 m^3/hr of oxygen.

The cleaning is performed with a uniform movement of the burner held at an angle of 30 - 45° to the surface and with a speed of 0.5 to 10 m/min. The cleaning of dry and porous layers, such as rust, takes very little time, while paint, lacquers and other hard to peel-off materials are most time consuming, because they do not peel-off, but get carbonized and burn.

In practice, cleaning is performed at a rate of 20 m^2 of surface per hour with acetylene consumption equal to 0.1 - 0.4 m^3 for each m^2 of cleaned surface.

SOLDERING

Soldering is the process of joining metals in which the joined surfaces remain solid while a molten easy melting metal, the solder is introduced into the clearance between the two parts, moistens their surfaces and solidly joins them after cooling and hardening of the solder.

Soldering requires less heat than welding, making it more economical in many cases. Another favorable feature is the absence of distortion of the metal without affecting its properties.

Soldering may be hard, with a solder based on copper, silver and other alloys, and soft using solders based on tin, lead, etc.

The composition of most widely used solders is shown in Vol.6, Chapter VI.

The composition of a few nonstandard solders is shown in Table 24.

Solders may be used in the shape of rods, ribbons, shot, paste mixed with flux, etc. Most economical are solders shaped in wire contours or foil gaskets which may

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be bent or shaped to resemble the shape of the joint.

Table 24

Nonstandard Solders

Type	Sn	SI	Chemical Analysis, in % Cu	Zn	Ag	P	Al	Melting Temperature, in 0°C	Solder Characteristic	Metals Suitable for Soldering
LOK 59-1-03	0.7-1.1	0.2-0.4	58-60	OST	-	-	-	800	Solid Viscous	Copper, bronze, steel
MFS	-	-	OST	-	-	7.5	-	825	Freely flowing Brittle	Copper and its alloys
PSrMF	-	-	"	-	14.5	4.5-5.5	-	700	Substitute for PSr-25	
15-80-5		-	-		15.5					
-	63	-	-	36	-	-	1	-	Soft	Aluminum and its alloys
-	-	5.2-6.5	25-29	-	-	-	-	525	Hard	Ditto

<u>Fluxes used for Soldering</u>. Fluxes are used to remove from the surface films of oxides and other admixtures which hinder the moistening of the surface by the solder. A few of the fluxes used for hard and soft soldering are described in Table 25.

Fluxes are used in powdered form or as pastes, powdered or smeared on the places to be soldered. They also may be coating the rod of a solder.

Lately, fluxes are used in liquid form sprayed by the flame, or as a vapor carried in the gas fuel.

Most of the fluxes containing salts are the cause of joints corroding after soldering. Especially, this tendency is strong in fluxes used for soldering aluminum, therefore, the remnants of flux after the soldering is over, should be removed.

Best for soldering are joints having a large surface (for example, overlapping joints, beveled edges, etc) because the contact with the solder is distributed over a larger surface. It is therefore advisable to increase, inasmuch as possible, the area of contact and to avoid joining parts at an angle with each other

Very often, the solder is not as strong as the soldered metal. The resistance to deterioration of the soldered joint increases with the decrease in the layer's thickness.

Table 25

Fluxes Used in Soldering

Component	Content in %	Purpose	Component	Content in %	Purpose
Fluxes for hard soldering			Fluxes for soft soldering		
Borax	100	Soldering of steel, copper alloys at t = 800°C	Zinc chloride Water	10 - 30 70 - 90	Soldering of iron, steel, copper and copper alloys
Boric acid Borax Fluorite	70 21 9	Soldering of stainless steel, heat-resistant alloys with brass at t · 900°C	Zinc chloride Ammonia chloride Water	25 - 30 5 - 20 50 - 70	Ditto, flux more active
Boric acid Borax Fluorite Impurity	80 14 5.5 0.5	Ditto	Zinc chloride Ammonia chloride Vaseline Water	20 5 74 1	Ditto, flux in form of paste
Boric anhydrate Fluorite Potassium fluoride borate	35 42 23	Soldering of stainless, structural, and heat-resistant steels and copper alloys with silver solders	Saturated solution of zinc chloride in H_2SO_4 Rosin		Soldering of copper and copper alloys Soldering of copper and copper alloys
Borax, melted fluorite or sodium fluoride, zinc chloride, sodium chloride	80 - 90 10 - 20	Soldering with silver solders	Saturated H_2O solution of zinc chloride iethanol Glycerine	34 33 33	Paste for soft soldering with a torch
Borax Zinc chloride Marganate	60 38 2	Soldering cast iron	Zinc chloride Sodium fluorite	95 5	Soft soldering of aluminum
			Lithium chloride Potassium fluoride Zinc chloride Potassium chloride	35 - 25 12 - 18 8 - 15 40 - 59	Hard soldering of aluminum

The clearance between two parts to be soldered should be within the limits of 0.55 - 0.15 mm. In joining large parts, a clearance not exceeding 0.25 mm is acceptable.

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Placing the parts too tight, or pressing each other, is not advisable as it prevents the penetration of the solder.

A sample of well done soldering joints is shown in Fig.16.

The surfaces should be carefully cleaned of oxide films and of dirt before the soldering. Etching of the surfaces is recommended.

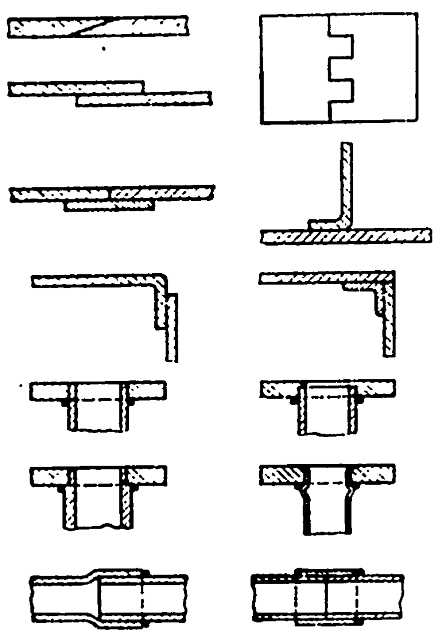

Fig.16 - Samples of Soldered Joints

In mass production, or when soldering is complicated, some kind of a device to hold the soldered parts in place is necessary.

If the soldering requires that the work is to be done in several steps, in such a case, a solder with a lower melting point should be used for each of the following steps.

The following methods can be differentiated: 1) local tempering and 2) general tempering.

The heating methods in soldering are: a) by the flame of combustible gases or vapors mixed with oxygen or air, b) by electric energy (arc, contact resistance, induced currents).

These methods are used when heating of a particular place is required. The heating of the entire work is performed in a) furnaces, b) in baths (metallic or salt), c) in forges.

Heating with a gas-oxygen flame, which in most cases is a oxyacetylene flame, is widely used in hard soldering, especially when only local heating is required. Burners used in soldering are the ordinary welding torches (cf. "Gas Welding", see later in text), special burners with widened soft flames and burners burning a

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kerosene-oxygen mixture. Heating by gas mixed with oxygen is simple, may be applied in many jobs, has good productivity and may be easily automized.

Heating with air-gas flames is preferable for soft soldering, but it is permissible to use copper phosphide and silver solder for small parts.

These burners use acetylene, methane, illuminating gas, propane, butane and others. There are also burners using liquid fuel (gasoline or kerosene) under pressure of 0.5 - 2 atm. These liquids enter a vaporizer and, as a stream of vapors, mix with air to form a high temperature flame.

Heating by electricity in hard soldering is effected by an arc from a carbon electrode. A quick heating and melting of the solder by this method, however, creates difficulties when handling thin parts which may easily become burned and the soldering becomes hard to control. This method, therefore, may be applied only in soldering large parts not requiring extra good work.

Good results and high productivity may be obtained by heating a long open seam with an electric arc indirectly.

Electric contact soldering is applied in soldering small parts and in soldering small parts to be joined to larger parts. The soldering unit APP-0.5 is applied in the contact soldering by silver solders of ribbon-shaped saws. With this unit it is possible to join saws 0.3 - 0.8 mm thick and up to 50 mm wide. The universal-type unit APT with a power of 6.5 - 15 kv-amp heats the place to be soldered which is held tight by tongs with graphite electrodes. These units are used in soldering of hard alloys to cutting tools.

The induction method using hard solders is effected by heating with high frequency currents, it is very productive and produces a good and clean joint.

More often, the frequency used is 8000 cycles. In use are also tube generators. The inductor windings have the contour of the parts to be soldered and is positioned along the soldering line. The heating may be controlled with precision and may easily be automized.

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The contact method of heating is widely used in soldering with soft solders. For this work are used soldering irons weighing 0.2 - 1 kg and made of red copper. The tip of the soldering iron is sharpened to an angle of 30 - 40° and has several facets. The soldering heated to 450 - 500°C is applied together with the solder to the required place already covered with flux where it is heated and moistened by the solder.

Soldering by the contact method of heating may also be automized.

The method of all-over heating in a forge is known for a long time and is used in soldering with brass and copper. By this method, the parts are fastened together and are heated in a forge by gas or charcoal. The solder and the flux are applied after.

One of the latest methods is soldering in furnaces. Easily attainable is the soldering in muffle furnaces. Best results are obtained in the chamber or tunnel-type of furnaces containing gas (more often hydrogen) for reducing purposes. The parts assembled in certain devices together with the solder and flux are placed in the furnace and are heated in the reducing gas which prevents oxidation and reduces the oxides of copper, iron, etc. As a solder, copper is used more often than others because of its ability to penetrate and to produce a strong joint. After reaching a temperature exceeding by 50 - 80°C, the melting point of the solder, the parts are cooled in the same reducing medium to 250 - 400°C. At this temperature the parts may be taken out in the air without fear of them becoming oxidized. This method is economical and may be applied in mass production.

High productivity and quality soldering are attained by baths into which the parts, or the assembly of parts, are immersed. In soft soldering, the bath is filled with solder, the parts already covered with flux at the right place are immersed into the bath and in 5 - 20 sec it is taken out with the excess of solder trickling down.

The same method is used with a copper-zinc solder, for example in soldering

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bicycle frames. In this operation, the part surface is covered with a layer of molten flux, while the portions not to be soldered have a protective layer of graphite.

Baths containing a mixture of molten potassium chloride with barium chloride are used for hard soldering. The parts with gaskets of solder are immersed in the bath. The molten salt dissolves the oxides, aids the molten solder to moisten the required places and protects the part from oxidation, after it is taken out in the air.

The S-35 unit, which is a salt furnace for heat treating, may be used for the work described above. It operates with a power of 35 kw and has a maximum productivity of 40 kg/hr. Another suitable unit is the S-75 with a power of 75 kw and with a maximum productivity of 70 kg/hr.

The Mechanization of Soldering. Automized and mechanized soldering is highly developed in industries dealing with the production of metallic packages, radios, and instruments, etc.

The soldering machines, as a rule, are specially adjusted to the work required by a particular product.

For example, in the packaging industry, the machine performs every operation required for the production of the article from a metal strip, with the soldering of the seams by a sharp flame included. In machines based on the method of immersion, the parts hung by a chain are immersed for the required time in the bath, are then taken out and proceed to the next operation.

In machines based on the induction type of heating, the parts to be soldered are carried by a conveyor and pass between the inductor windings.

ARC-WELDING IN INERT GASES

In the arc-welding in inert gases, the welding zone is isolated from the air be streams of inert gases, such as argon and helium. Argon and helium by not react chemically with any other element, and for this reason, the welding bath and the welding rod are not subjected to oxidation or to nitrogen saturation. The characteristics of these gases are as follows:

	Argon	Helium
Atomic weight	39.9	4
Weight of 1 m^3 in kg	1.78	0.178

The composition of Argon used in industry, in %, is:

Class	Argon (minimum)	Oxygen (maximum)
1st	99.7	0.05
2nd	99.2	0.2
3rd	98.4	0.5
Technical	90-88	0.4

Argon and helium are delivered in tanks under a pressure of 150 atm and are delivered for welding through a reducing valve.

Welding in inert gases insures a high productivity, obviates the use of fluxes, is simple in operation and may easily be automized.

Nitrogen, carbon dioxide and a few other gases are sometimes used in the welding of certain metals. Arc-argon welding is more in use than arc-helium welding. Each one of them may be performed with the use of a melting or nonmelting electrode. Helium creates a great quantity of heat in the arc and, consequently, a greater depth of melting.

In the welding with a nonmelting electrode, welding arc (1) (Fig.17) is in an excited state between the welding product (2) and the tungsten electrode (3) which is surrounded by a pipe tip through which argon or helium flow continuously. The inert gas produces around the bath (4) and around the welding rod (5), which is immersed in the bath, a solid cover (6) which displaces the oxygen and nitrogen

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of the air.

The welding is performed with the air of an electrode holder consisting of a handle with a nipple to bring the gas and a clamp to connect the current. The small stem ends in a head, into which is clamped a tungsten electrode, and in a nozzle which forms around the electrode a ring-shaped opening.

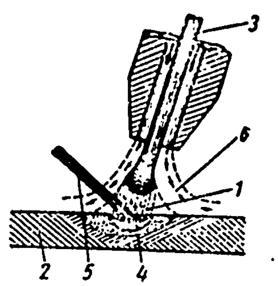

Fig.17 - Sketch of Arc-Welding in Inert Cases

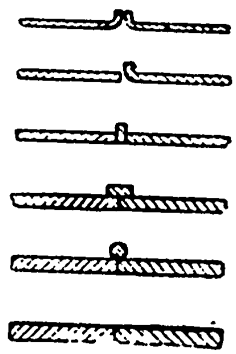

Fig.18 - Sketches Showing Seams Prepared for Arc-Welding

There are electrode holders EZP-1 for currents of up to 200 amp and EZP-2 for up to 300 amp.

The welding arc may be produced either by direct or alternating current and by the use of ordinary welding equipment capable of current regulation from 30 amp and higher. To improve the stability of the arc, an oscillator of high frequency is used.

The nonmelting electrode is used in the welding of thin-wall products made from sheets or tubes with a thickness of 3 - 5 mm. From the economic standpoint, it is the best method for welding products which cannot be welded by another method. To this group belong aluminum, magnesium, copper and its alloys, titanium, molybdenum, stainless steel, heat-resistant and acid-resistant steels, and alloys with a high content of chrome.

In the welding of thin materials there should be a lining placed under the seam to prevent the metal from flowing out and its oxidation from the other side of the material. The welding may be effected with a welding rod and also without it, which changes the preparatory operation correspondingly. Sketches of preparing the seam are shown in Fig.18. The edges, before the welding should be cleaned of

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the oxides, if any.

In hand welding, the electrode holder is to be set along the seam axis inclined at an angle of 15 - 25° from its normal position to the surface. When a welding rod is used, it is to be set at an angle of 90° to the electrode axis.

Table 26

Welded Metal	Alternating Current with Added High Frequency Current	Direct Current	
		Direct Polarity	Reversed Polarity
Aluminum and its alloys	+	–	–
Magnesium and its alloys	+	–	+
Copper and its alloys	–	+	–
Steel with high chrome content	+	+	–

Table 27

Thickness of Welded Metal in mm	Diameter of Tungsten Electrode in mm	Current Intensity in amp	Gas Consumption in liters min	
			Argon	Helium
1	2 - 3	40 - 120	3 - 5	5 - 8
1,5	3	50 - 200	3 - 6	5 - 9
2	3 - 4,5	60 - 250	4 - 6	6 - 9
3	3 - 4,5	80 - 350	4 - 7	6 - 10
5	4,5 - 6	100 - 400	5 - 8	7 - 12
10	6	125 - 500	7 - 12	10 - 18

In the welding of thin sheets, the welding rod is to be laid along the seam, with the welding proceeding rapidly from right to left.

Tables 26 and 27 may be used for obtaining the information required in selecting the current and conditions suitable for the arc-argon welding.

The welding speed is 0.4 - 0.6 m/min for thin sheets and is 0.2 - 0.3 m/min for thicker materials.

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Larger current amperages are required in welding coppers, steels and similar metals, and a smaller amperage is required for the welding of light metal and with a reversed polarity.

In the mechanized welding with nonmelting electrodes, special electrode holders with a floating device to maintain a steady arc clearance are in use. The electrode holder tips are water-cooled.

In welding with a melting electrode, the welding arc is in an excited state between the product and the electrode wire which is fed through the electrode holder. The inert gas, flowing through the ring opening of the electrode holder, surrounds the welding zone. Unit GDU is designed for welding by this method; it consists of a control box, a feeding mechanism and an electrode holder. In a semi-automatic unit, the electrode holder has the shape of a pistol, with the aid of which the welding may be performed in any position of space. For the automatic welding of longitudinal seams, the unit GDU is installed on a self-propelling carriage with the electrode holder held fast in a support.

The welding wire with a diameter of 1.2 to 2.5 mm is fed with a speed controlled within the limits of 2.5 to 16 m/min. The carriage moves with a speed of 0.1 to 4 m/min.

The welding with a melting-type electrode is characterized by the concentrated emission of great amounts of heat which causes the extension of the welding deep into the material (up to 10 - 12 mm, in aluminum) and also by a high productivity.

The current intensity of reversed polarity is 100 - 300 amp, the consumption of argon is 0.4 - 0.5 m^3/hr, of helium 30 - 40% more.

ATOMIC-HYDROGEN WELDING

Essential Elements of the Process

Atomic-hydrogen welding belongs to the group of gas-electric (electrochemical) methods. Essentially, the process consists in obtaining, under the action of the

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high temperature of the arc, of atomic hydrogen, which recombines into molecules on the surface of the welded metal with emission of considerable quantities of heat.

The arc is burning between two nonmelting types of electrodes (tungsten or carbon) in the atmosphere of hydrogen, or of hydrogen mixed with nitrogen. The flame formed by the burning hydrogen protects the metal from the action by the air*.

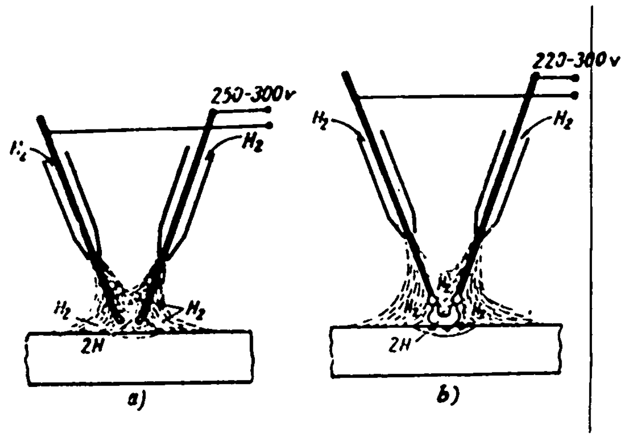

Fig.19

The thermal dissociation of the hydrogen taking place in the arc is proceeding with the absorption of great quantities of heat which is given out, when the hydrogen atoms recombine on the metal surface. (With an arc temperature of 4000°C, the rate of dissociation α = 0.72.) This may be represented as follows:

$$2H \rightleftharpoons H_2 + 100{,}000 \text{ calories/hr mol}$$

Depending on the amperage of the arc and the distance between the electrodes, the arc may be of the quiet (Fig.19a) or ringing type (Fig.19b). The ringing arc has the shape of a fan, emits a sharp sound and is characterized by its great intensity, greater than the quiet arc which is used in welding of thin materials.

The high potential required for the ionization of hydrogen (V_j = 13.5 v) and the cooling action of the hydrogen stream, which lowers considerably the temperature of the electrode tips, make a higher voltage necessary for igniting the arc in atomic-hydrogen welding, (the voltage required for igniting the arc is 250-300 v,

* N.N.Bernados was the first to propose the method of using an independent arc in the atmosphere of hydrogen, in 1883.

while the voltage required for just burning the arc is, depending on its length, 30 - 45 v for a quiet arc and 60 - 210 v for a ringing arc).

In atomic-hydrogen welding, the welding rod is fed into the liquid bath sidewise, and it may be added, that the methods of melting the metal, forming the groove for the seam, the technique of handling the burner - are all similar as in gas welding.

Besides its action in generating heat and protecting the metal, atomic hydrogen is good in reducing the oxides of almost every metal. The welding process proceeds with decarbonization of the metal and with some saturation of tungsten by the liquid bath into which the tungsten falls during the vaporization of the electrodes, as may be seen from the following data:

Element	Welded Metal	Welding rod metal	Deposited Metal
Carbon	0.11	0.11	0.05
Manganese	0.43	0.44	0.42
Silicon	0.03	0.04	0.03
Sulphur	0.011	0.028	0.022
Phosphorus	0.021	0.027	0.024
Tungsten	absent	absent	0.07

The Equipment for Atomic-Hydrogen Welding

Atomic-Hydrogen Units. Units of the type AGES-75-2 (Fig.20) are designed for manual welding with a current from 20 to 75 amp and with the use of a tungsten electrode with a diameter of 1.5 - 2.3 mm. The unit consists of a transformer RTGES-75-1, a welding current regulator ATGES-75-1, control instrument cabinet, a burner with its controls and a portable push-button KCh-122-2M.

The transformer converts the circuit voltage of 220/330 v to 330 v. Current regulation is by a reactor.

When the duration of the welding cycle is equal to 10 min and PV = 65%, a current of 75 amp is suitable. The power consumed by this unit is 23.5 kw. Certain devices in this unit are designed for the safety of the operation and of the personnel. When the unit is improperly used, or damaged, a shrill signal will warn the welder of high voltage in the parted electrodes. The operation is started by pressing the push-button where it is marked with the letter P (contacts 22 and 23 in Fig.20).

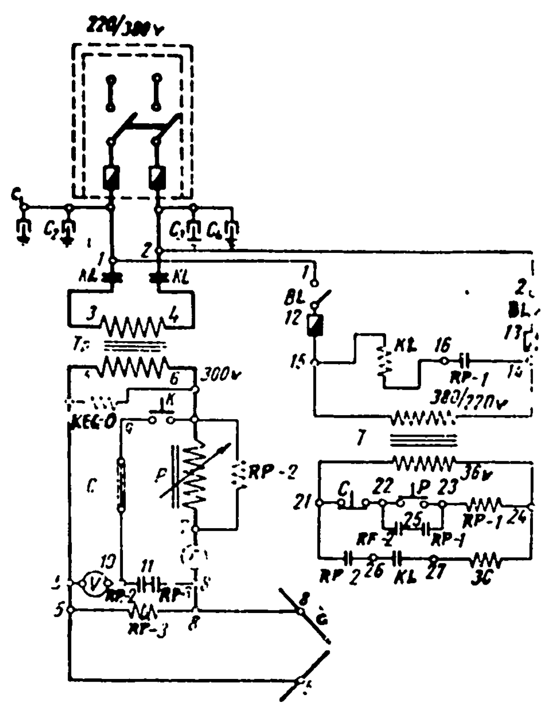

Fig.20 - Principal Diagram of Unit AGES-75-2

To turn the welding current off, the push-button with letter S (stop) is pressed.

Condensers C_1, C_2, C_3, and C_4 are installed to lessen the radio interference.

<u>The Unit Av-40-a</u> (Fig.21) consists of a transformer (1), a choke coil (2), a contactor (3), button switch (4), a gas manifold (5), lamp signal system (6). The unit is designed for a primary voltage of 380 v and a secondary of 320 v.

The current is regulated by switching to the proper outlet of the choke coil, with the regulation kept within the limits from 15 to 49 amp.

The primary is bank wound (section winding) and has three stages - a primary voltage of 340, 360, and 380 v.

In addition, the primary winding has another section with outlets to the plug switch, which regulates the current to the heater of the cracking device.

This switch is able to regulate the current in six stages producing currents

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of different intensity when needed by the heater of the cracking device.

The electromagnetic switch (the contactor) consists of two windings for the core (a pull-in and holding), contacts to the circuit and a spring.

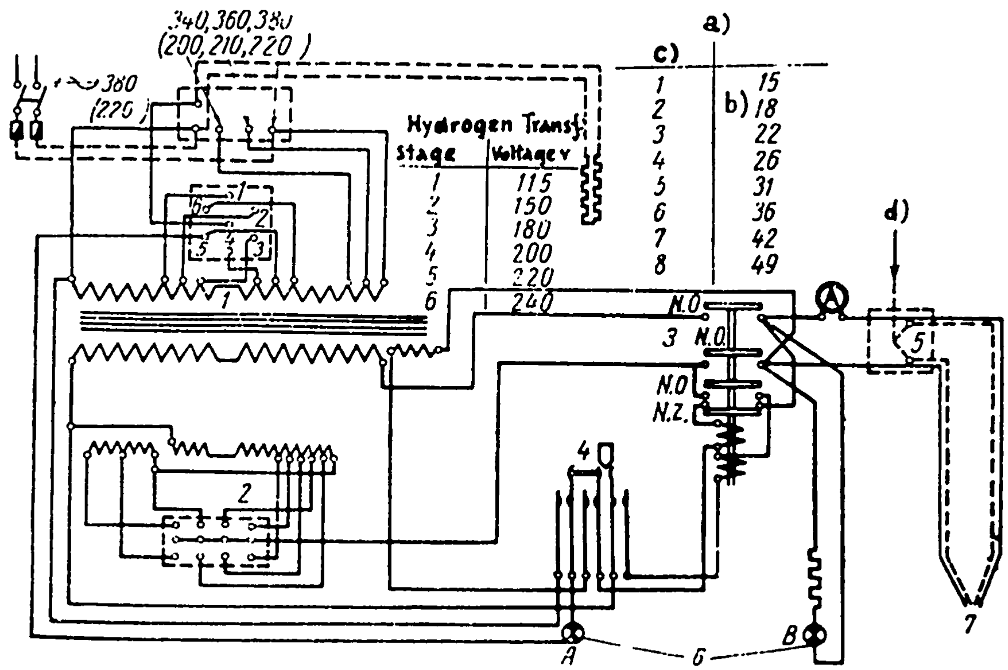

Fig.21 - General Diagram of Unit AV-40a

a) Choke coil;outlet; b) Currents; c) Stage;

d) Hydrogen or dissociated ammonium

The push-button is for opening and closing of the circuits to the contactor and to the signal system consisting of two tubes A and B.

Tube A is connected to the transformer primary and its purpose is to warn the welder when the burner voltage reaches 50 volts. Tube B is connected to the electrodes and warms the welder of trouble with the contactor.

When push-button (4) closes the circuit of electrodes (7) it produces a voltage from the tertiary winding of the transformer. The bringing of the electrodes together closes the circuit of the pull-in winding of the contactor which closes the normally open contacts (n and o) of the welding circuit and of the holding winding circuit. At this, the normally closed contacts (n and z) of the pull-in winding become open.

Next to happen is the rapid parting of the electrodes which produces the arc, the length of which is regulated by a wheel device of the burner. When the arc fails it will end the voltage drop in the choke coil which supplies current to the holding winding of the contactor.

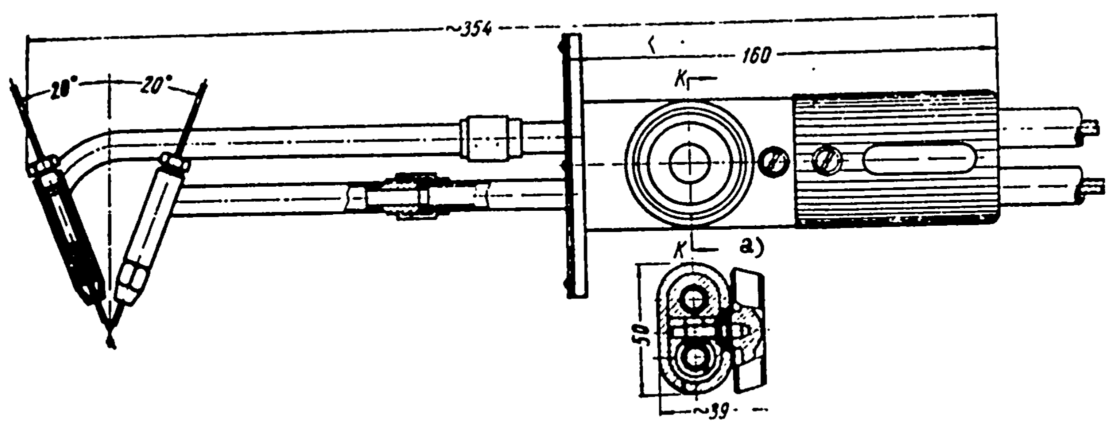

Fig.22

a) View along KK

When this happens, the contactor spring will open contacts (n and o) thereby removing the high voltage from the electrodes.

Burners. The burner type GEG-1-1 is designed for a current up to 100 amp. The unit is heavy and bulky. It is used in welding materials of relatively large thickness.

The Burner G-21-1 (Fig.22) is part of the unit AV-40-a, it is not heavy, and is designed for the welding of metals of moderate thickness.

The supply of current and gas in atomic-hydrogen welding is by a gas manifold furnished with special pipes containing inside flexible copper conductors. If the

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welding place is inaccessible, the burner tips may be bent or made longer.

Hydrogen Tanks. Tanks belonging to group A of GOST 949-41 are seamless steel vessels used for transporting and storage of gaseous hydrogen under a pressure of 150 atm.

Unlike the tanks used for noninflammable gases, this tank is equipped with valves having its rod with a left threading.

The hydrogen tanks are tested once in five years. The rules for storaging, transportation and use are the same as for oxygen tanks, but taking into consideration the possibilities of explosion or inflammation.

The Hydrogen Reducing Valve does not differ from an oxygen valve.

Any oxygen reducing valve will fit, provided its rod has a safety nut.

Ammonium Dissociators (cracking devices). The atomic-hydrogen process may be effected by using either hydrogen, or by a mixture of hydrogen with nitrogen. Such a mixture is normally obtanned by the dissociation of ammonia in a special cracking device.

The advantages of using dissociated ammonium instead of pure hydrogen are many, some of them are: the plentiful supply, the comparatively safety of operation and economies resulting from the large quantities of gaseous ammonium given out by the liquid. One liter of liquid ammonium storaged in tanks is equivalent to 0.81 m^3 of gas, or 1.62 m^3 of nitrogen-hydrogen mixture containing by volume 25% N_2 and 75% H_2. An ammonium tank will supply 7.3 times as much of hydrogen than may be obtained from a hydrogen tank of the same volume.

The nitrogen, formed as a result of the dissociation of ammonium, has no damaging effect on the welded steel because, in the presence of hydrogen, an exothermic division of the iron nitrides takes place:

$$2Fe_4N + 3H_2 \rightleftharpoons 8Fe + 2NH_3 + 13{,}080 \text{ calories}$$

The nitrogen content in an α-solution usually does not exceed 0.11 - 0.12%.

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The less intensive cooling action of ammonium, as compared with hydrogen, makes it possible to use a lower voltage for the ignition and burning of the arc, on the other hand, the consumption of tungsten will be higher by 10 - 20%.

The dissociation of ammonium is effected in the presence of a catalyzer at a temperature of 600 - 650°C.

<u>The Cracking Device DK-1</u> (Fig.23) consists of a heater and cylindrical chambers for the catalyst surrounded on the outside with a coil heat exchanger. The catalyst chambers are heated on the inside electrically. The cracking device is enclosed in a jacket to avoid heat losses.

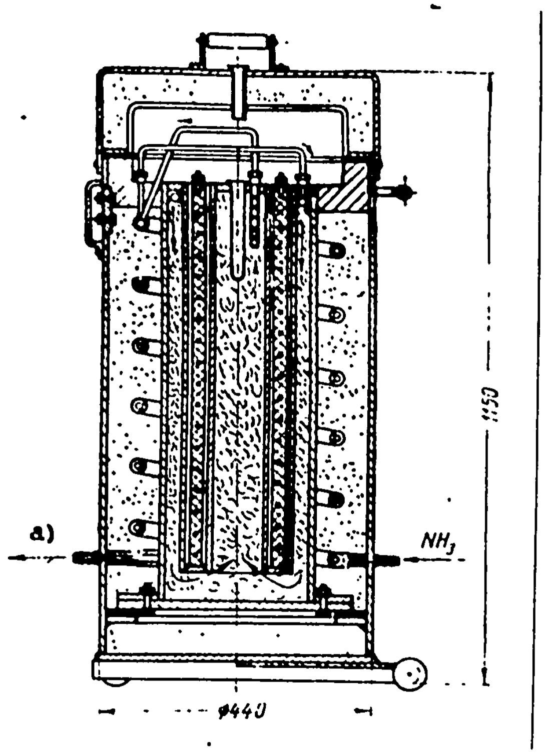

Fig.23

a) Nitrogen-hydrogen mixture

The gaseous amonium leaves the tank under a pressure of 0.2 - 0.3 atm, enters the outside pipe of the heat exchanger, then, in a dissociated state proceeds to the inside pipe of the heat exchanger, from there it proceeds into a pipe to the water separator and burner.

The catalyst is usually a natural magnetite or slightly oxidized iron shavings. The catalyst must be restored before the cracking by gas burning for 18 - 24 hrs. The useful life of the catalyst is six months.

There is another catalyst, the nonbaking type prepared in the shape of small balls which roll easily inside the coil and are loaded in the catalyst chambers.

The use of nonbaking catalysts simplifies the cracking unit which may be built by welding without flanges. The temperature is regulated by a thermocouple placed

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into a special pocket of the inside catalyst chamber. The incandescence of the cracking winding may be regulated in three ways: by a rheostat able to keep the current within the limits of 10 - 20 amp; by switching the transformer primary winding (if the cracking is connected to the AV-40-a unit); by a thermostat connected in the cracking circuit.

The cracking unit is provided with a safety valve designed for a pressure of 0.5 - 1 atm with a warning device if the pressure exceeds that limit.

The use of a hydrogen valve in an atomic-hydrogen unit when welding with dissociated ammonium is not permitted.

The nitrogen-hydrogen mixture leaves the cracking unit at a temperature of about 40°C with a certain quantity of water in it which is removed in a special water separator. The separator is either a vessel with baffles, or a vessel filled with calcium chloride or with silicate gel.

The cracking unit DK-1 is designed for a 220 volt circuit, consumes 4.5 kw, when the productivity is up to 2.5 m^3/hr. A general diagram of feeding the arc with dissociated ammonium is shown in Fig.24.

<u>The Combination Cracking Unit Designed by Engineer M.N.Vishnevskiy</u> (Fig.25) performs two functions by simultaneously supplying the arc with current and dissociating the ammonium.

In this combined unit, the heater coil is at the same time the winding of the choke which feeds the arc with current. The path of gas in this cracking unit is considerably longer, as the gas has to pass through a labyrinth of channels formed by three pipes, the space between which is filled with the catalyst. Such a design insures a more intensive dissociation and makes it possible to obtain a better productivity with this smaller (in size) unit.

The method of operating this unit is as follows: The gas passes through nipple (1), water separator (2), and heat-exchanger pipe (3) and proceeds to the labyrinth of catalyst chamber (4) formed by three pipes (5), (6), and (7) where the gas

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is broken into hydrogen and nitrogen; from there, in a state of nitrogen-hydrogen mixture, the gas enters the heat exchanger (8). Cooled by the ammonium stream moving counterwise, the gas passes through the water separator (2) and proceeds

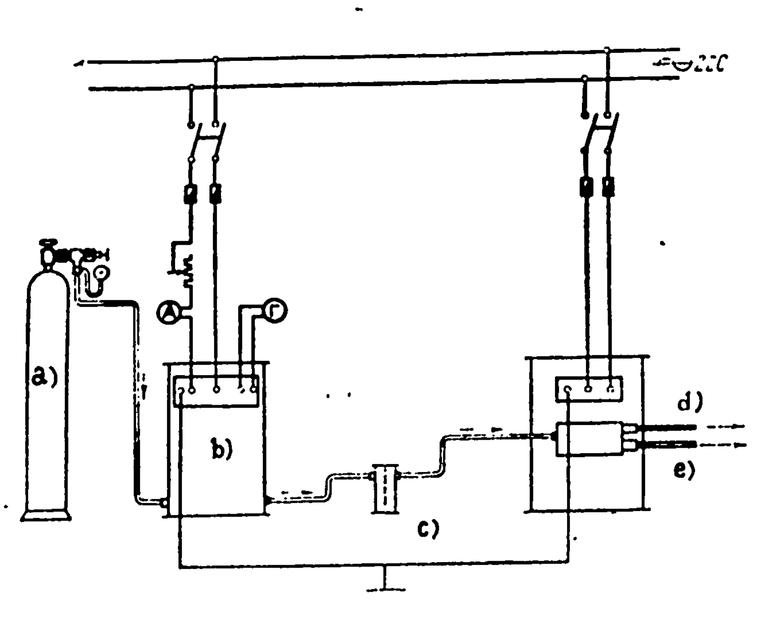

Fig.24

a) Ammonium; b) Cracking; c) To burner; d) Atomic jydrogen init; e) Ammonium-air equipment

through a pipe to the burner.

Just as in other dissociating units, there is an isolating jacket on the outside of which there is a panel (9) with a rheostat for choke coil winding (10), thereby insuring the required current regulation.

<u>Ammonium Tanks</u>. The liquid ammonium tanks are made of steel and are painted yellow and have a capacity of 20, 30, 40, and 60 k of liquid ammonium.

The rate of filling is no more than 1 kg of ammonium for each 1.86 m^3 of the tank volume.

<u>The Ammonium Valve</u> serves to regulate the ammonia gas pressure and its consumption as it leaves the tank.

The valve is made of steel and is designed as a needle valve.

The pressure is measured by a manometer with glycerine or oil filling its siphon tube. The pressure may also be measured by a mercury manometer.

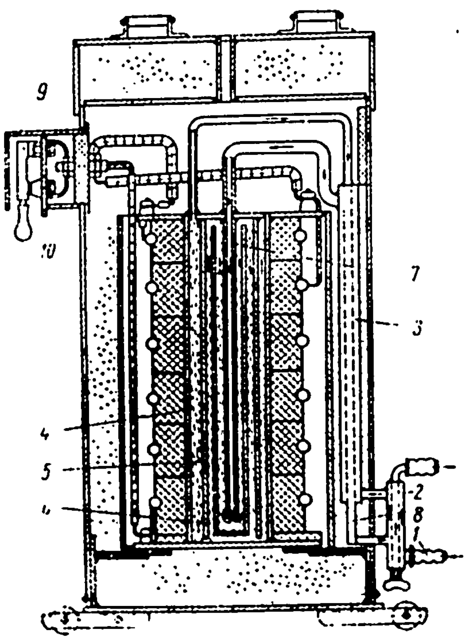

Fig.25

Electrodes. Electrodes for atomic hydrogen welding are made of tungsten or carbon, although the carbon electrodes are not widely used. Most widely used are tungsten rods with a diameter of 1 - 3 mm.

The best quality (more solid) is in the rods of small diameters (1,1.5, and 2 mm). The length of the electrodes is from 200-250 mm, maximum.

Carbon or graphite rods are usually used without wicks. Diameters of 6-8 mm will make these burn longer in the process of welding.

The General Technology of Welding

Due to its good restoring properties, the atomic hydrogen flame is successfully used not only in the welding of ordinary low carbon steel, but also in the welding of structural, low alloyed, stainless and heat-resistant steels and aluminum alloys. In the welding of steels, the use of flux is not required.

Especially good results by the atomic hydrogen process are attained in the welding of low carbon steels. Because of its low carbon content, almost no decarbonizing is noted in the welded material and the seam is solid and possesses high plastic properties, namely: yield point of 38 - 40 kg/mm^2, elongation of 25 - 30%, impact viscosity of 18 - 18 kg/mm^2 and angle of bend 180°.

With steel 2 - 2.5 mm thick, the atomic hydrogen welding is more productive than the manual arc, or even gas welding.

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With the increase in thickness, the productivity of this method decreases and becomes uneconomical.

The types of welding joints in atomic hydrogen welding are the same as in gas welding. Of the types more suitable are butt joints, especially with bent edges and also angle joints and end joints, where the welding may be effected without the use of welding rods.

The heat capacity of an atomic hydrogen arc and its thorough melting ability depend on the voltage, amperage, gas of consumption and also depend on the position and the angle of inclination of the burner in relation to the welded metal. The arc voltage depends on its length and, particularly, on the distance between the electrode tips. With sufficient current and gas, the greater this distance between the tips - the more will the arc get blown away from the electrodes and will start giving out a shrill sound, in other words, will become a ringing arc. Such an arc, as mentioned before, has a greater heat capacity than a quiet arc and is, therefore, used in the welding of metal more than 2 mm thick; the burner in such an event is so positioned that the end of the arc touches the surface of the metal. The amperage and gas consumption depend on the thickness of the metal welded and on the diameter of the electrodes.

In the welding of steel with comparatively low thickness (1 - 2 mm max.) by using a quiet arc, the current intensity is 10 - 25 amps, and gas consumption is 500 - 800 liters/hr. With a ringing arc, the current required is 25 - 75 amps and gas consumption is 800 - 1500 liters/hr.

The operating conditions in atomic hydrogen welding of low carbon steels and aluminum, also economic and technical data resulting from welding of these metals by tungsten electrodes, are all shown in Table 28.

TECHNOLOGICAL CONSIDERATIONS IN DESIGNING MACHINE ASSEMBLIES AND PARTS FOR WELDING

From the practical standpoint, a good design of machine parts to be made by

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welding must insure the required quality attained at a minimum time and cost. Under cost is understood the consumption of metal, especially, the nonferrous metals and

Table 28

Thickness of Material in mm	Type of Joint	Tungsten Electrode Diameter in mm	Current Intensity in amp	Time	Per 1 meter of Seam		
					Electric Energy kw hrs	Tungsten in mm	Hydrogen liters
		Low carbon steel					
1	Butt joint without beveling edges	1,5	26-32	5.5	0.2-0.3	9	0
2		1,5	28-34	5.0	0.3-0.4	9.5	35
3		1,5	32-38	7	0.4-0.5	10.5	40
4		1,5	35-44	8	0.5-0.7	12	55
5		3	37-50	11	0.7-1	6	80
6	Butt joint with bevel edges	3	40-56	14.5	1-1.4	6	120
7		3	40-60	19	1.4-2	14	180
8		3	42-65	25	2-3	23	250
9		3	43-66	31.5	3-4	34	350
10		3	44-70	39	3-5	50	450
11		3	45-70	46	4-6	73	560
12		3	45-70	53.5	5-7	95	700
		Aluminum					
1	Butt joint without beveling edges	1.5	28	5.5	0.3	27	45
2		1.5	31	4.3	0.3	29	30
3		1.5	33	4.5	0.3	12	55
4		1.5	35	5.8	0.4	12	75
5	Butt joint with bevel edges	3	37	7.3	0.5	5	95
6		3	39	8.8	0.6	5	110
7		3	42	10	0.8	13	120
8		3	44	11	0.9	20	125

high-grade steel.

The requirements for a practical design of welded parts and assemblies may be divided into general requirements for all methods of welding and special for certain methods of welding only.

General Requirements

1. In designing, it is necessary to take into consideration the general technological principle on which the process is based (Fig.26) and the best practical methods available (Table 29).

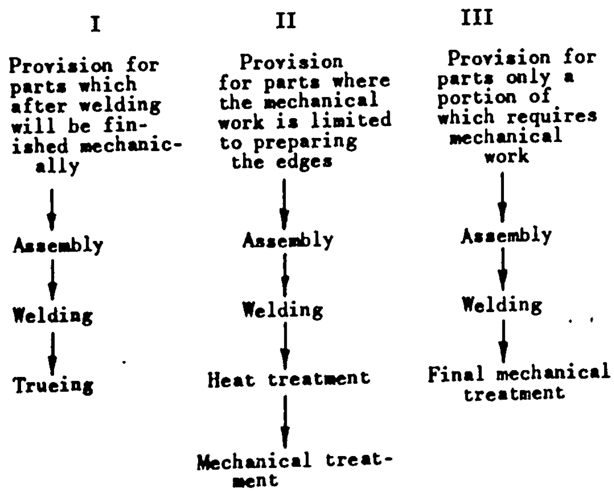

Fig.26 - Typical Technological Methods of Making Welded Parts

The Welding without Mechanical Treatment to follow (Fig.261), (so-called "hot mounting"). Sample variants: 1) the welding of a bumper part to the flange of the back axle cover of a passenger automobile. The part (1) (Fig.27a) with a pressed-in steel bushing (2) and the completely-finished pin (3) are butt-welded to flange (4). Variant (2): The welding of completely finished bushings to the rotating platform of an excavator consisting of three sections totaling 20 × 11.5 m (Bibl.47); Bushings (1) (Fig.27b) were set in rigid mandrils (2), which insured that the axis remained in line and also made sure the distance between the bushings remained the same. The advantages of "hot mounting": aids the mechanical treatment of the product. The negative side of "hot mounting": difficulty to make an assembly with precision. The field of application of "hot mounting": assemblies not requiring great precision and very large parts.

The Welding plus Heat Treatment plus Mechanical Treatment of the Finished Product (Fig.26 II) is illustrated by the following examples: Fig.27c, which is a welded bed of a metal cutting lathe, indicates the advantage of this method and its disadvantages. The advantages are: precision, no change in the geometrical shape of the assembly and absence of internal stresses. The disadvantages are: hard to execute and the long operating cycle. The field of application: assemblies requiring precision and assemblies requiring a considerable volume of welding.

<u>Welding plus Partial Mechanical Treatment</u> (Fig.26 III).

Example: a welded frame of a gear box (Fig.27d). The bearing shells have a rough machining before the welding; the final machining is effected when assembled

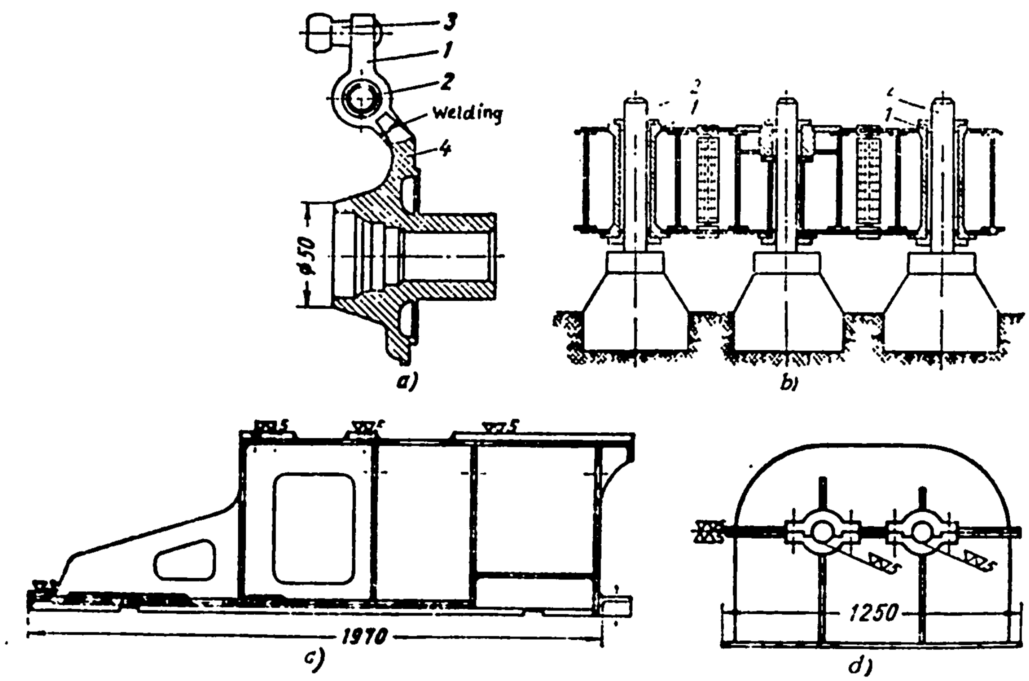

Fig.27 - Examples of Applying Various Basic Technological Methods in the Making of Welded Parts

after the milling operation on both halves of the gear box frame. The advantages of this method: less time spent in mechanical work and a smaller load for large machine tools. The negative side is: complicated shop work in preparing parts. The field of application: assemblies of parts having large dimensions requiring high precision.

2. The second requirement is the reducing to a minimum the volume of work by: a) reducing the number of parts going into a welded assembly, for example, using one thick sheet instead of several thin ones (Fig.28a), bending in place of

Table 29

General Characteristic of Basic Welding Methods

Type of Welding	Material most Frequently Used	Recommended Thickness in mm, or Cross Section of Welded Part	Basic Types of Welded Joints	Position in Space of Welded Seams
Manual, electric arc, metallic electrodes*	Steel Cast iron Aluminum and its alloys Copper Bronze Hard alloys	≤ 1 5 _ 1 ≤ 1	Butt, lap, shaped, bent edges, metal depositing Butt, metal deposit Butt Butt, edge bending Butt, metal deposit Metal depositing	Any position Lower position " " " " " " " "
Automatic** and semiautomatic*, melting metallic electrodes, under a layer of flux	Steel Aluminum and its alloys Copper	_ 3 _ 6 _ 4	Butt, lap electric riveting, metal depositing Butt Butt	Lower position " " " "
Electroslag**	Steel (structural)	_ 50	Butt	Vertical ring-wise
Manual, electric arc, carbon (nonmelting) electrode*	Steel (low carbon) Aluminum Copper	≤ 4 _ 1 _ 1	Edges bent ≤ 3 mm edges bent ≥ 3 mm butt ≤ 3 mm edges bent _ 3 mm butt	Any, except overhead Lower position " "
Automatic, non-melting electrode (carbon); copper: tungsten; aluminum under flux**	Copper and aluminum	_ 2	Butt	Lower position
Atomic-hydrogen***	Alloyed steel	≤ 8	Butt, shaped, bent edge	Any, except overhead
Electric arc, non-fusible electrode, in protective medium (argon)*	Stainless steel Aluminum and its alloys, magnesium alloys	≤ 4	Butt, shaped, bent edges, electric riveting	" "
Electric arc, fusible electrode, in protective medium (argon)**	Stainless steel, light alloys	≥ 2	Butt, shaped, bent edges, electric riveting	Lower position
Electric arc, melting electrode, CO_2 protection**	Steel	≥ 3	Butt, shaped	Lower position

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Type of Welding	Material most Frequently Used	Recommended Thickness in mm, or Cross Section of Welded Part	Basic Types of Welded Joints	Position in Space of Welded Seams
Gas***	Steel Cast iron Aluminum and its alloys, copper, bronze, brass, hard alloys	≤ 2 ≤ 10	Butt, bent edges Butt, metal deposit Butt, bent edges Metal depositing	Any position Lower position " " " "
Gas, under pressure*	Steel	Area up to 25,000 mm^2	Butt	Lower*
Termite	Steel	200 000 mm^2 and above	Butt	Lower position
Contact, butt, by melting**	Steel, aluminum	Steel area 25,000 mm^2 thickness over 0 7 mm***	Butt	Lower position*
Contact, butt, by resistance**	Steel, copper	Diameter of wire 10 mm	Butt	Lower position*
Spot welding**	Low-carbon steel Structural alloyed Stainless steel Aluminum alloys Heat resistant alloys	≤ 12** ≤ 10** ≤ 6**** ≤ 3 ≤ 3.5	Overlapping " " " "	Any, with the use of carrying tools: clamps, etc
Roller welding*	Special steel Hot rolled low carbon steel Stainless steel Aluminum alloys and copper alloys Heat resistant alloys	≤ 3***** ≤ 2.5***** ≤ 3***** ≤ 2***** ≤ 2.5*****	Overlapping " " " "	Lower* " " " "
Relief welding**	Low carbon steel	0 5 – 4	Overlapping	Lower*
T-Shaped,** contact	Same	≤ 150 mm^2 cross section of welded joint	Overlapping	Lower*
Cold**	Aluminum	≤ 10 ≤ 50 mm^2	Overlapping Butt	Lower* "

* Position usually the "lower" and is determined by machine design

** In nonmass production, usually up to 6 mm

*** In nonmass production, usually up to 10 000 mm^2

**** In nonmass production, usually up to 3 mm

***** In nonmass production, maximum thickness is less by 30 40%

Remarks: High precision required in preparing and assembly of parts for automatic (with flux), contact resistance and roller welding Productivity: 1) high, 2) very high, 3) moderate

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welding (Fig.28b), stamping in place of cutting or rolling (Fig.28c), substituting stiffening ribs by stamping out a re-enforcing shape (Fig.28d); b) reducing the

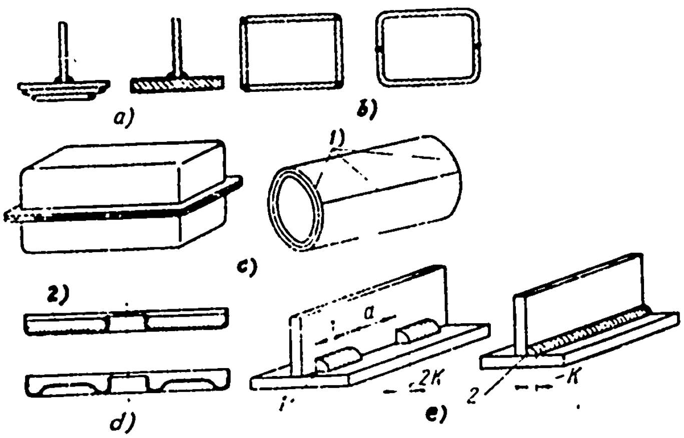

Fig.28 - Method of Reducing the Amount of Welding Work

1) Seam; 2) Rib

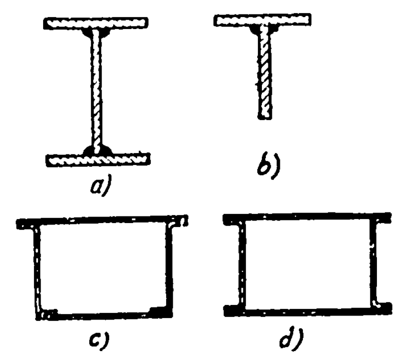

Fig.29 - Types of Welded Cross Sections

quantity of molten metal, for example, instead of interrupted seams (1) with arc 2k and metal volume W_1 (Fig.28c, left) weld a solid seam (2) with arch k and metal volume $W_2 = 0.5\ W_1$ (Fig.28e, to the right). Using the smallest angles possible, when preparing the edges for welding, to insure a good joint; also explore the possibility of joining parts without beveling the edges. Using such electrodes and welding rods that will permit a high degree of strength to a seam of minimum cross section without additional depositing of metal.

3. Reducing to a minimum the deformation and stress resulting from welding by: a) reducing the number of seams and volume of deposited metal; b) to arrange, inasmuch as possible, the symmetrical location of the seams in relation to the center of gravity of the welded product, (Fig.29a) is correct, but Fig.29b does not fulfill this requirement); c) to prevent the crowding of the seams and their crossing each other too often; d) the location of the seams should allow the assembly of

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parts before the welding; the spot-welded part (Fig.29c) does not fulfill this requirement, as the necessity of welding seams inside the part, before welding seams on the outside, is the cause of a considerable deformation; the design of part shown in Fig.29d is better, here, the seams may be welded in any sequence.

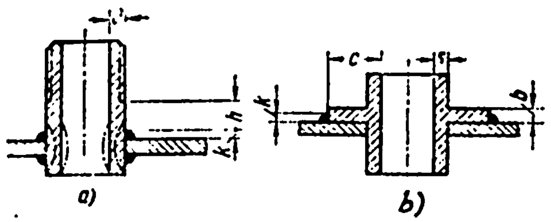

Fig.30 - Two Methods of Welding Bushings and Stems

4. Protecting the finished surfaces from damage during the welding by locating the seams away from such surfaces. Example: in the welding of the bushing (Fig.30a) its inside dimensions change, as shown by the dotted line, and the precision is lost; in the welding of the preliminary threaded stems, the distance h should be $5\alpha \leq h\delta \geq 5k$; the design of Fig.30b, when welded by an electric arc, will have the inside diameter unchanged, with $b \geq s$ and $c \geq 3k$.

5. Locating all finished seams in such a manner as to make the control and their inspection easy.

Special Requirements in Designing

Manual Electric Arc Welding. The method to be selected for preparing the borders and the edges for welding must be determined by the thickness and grade of the welded material, by the type of joint and its position in space and by the welding process (on one side or on both sides).

The basic methods of preparing the edges of a material made of steel are shown in Table 31, where all welding positions, except the horizontal, are shown in Fig.31a to d; the butt joints for a horizontal position are shown in Fig.31e to g; the shaped joints are shown in Fig.31h and i. The maximum thickness of the material welded manually without beveling the edges (Fig.31a) should be 4 mm, if one side is welded, and 6 mm if both sides of the steel are welded.

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In preparing the edges it is necessary, inasmuch as possible, to strive for a lower or vertical position (Fig.32a).

The welding of aluminum and its alloys is done without beveling the edges and with a clearance of 1 - 1.5 mm.

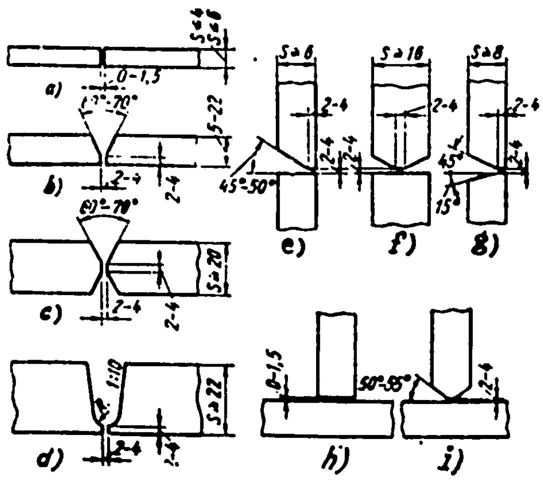

Fig.31 - Sketches Showing the Basic Methods of Preparing Edges for Welding Manually by Electric Arc

The Minimum Penetration k_{min} which can insure a satisfactory seam is determined by the thickness δ of the material, namely:

δ in mm	k_{min} in mm
> 4	3
4-8	4
9-15	6
16-25	8
> 25	10

In the Welding of Products with Thick Walls provision should be made for:

a) The ability to weld the basic seams without interruptions; this calls for "windows" (Fig.32b) in the event certain elements of the product cross each other. The size of the windows should be 80 - 100 mm;

b) Freely set seams; the junction of an inspection window cover (1) with the wall (2) (Fig.32c) fulfills this requirement, while Fig.32d does not;

c) Streamlined transitions at the joint from thick parts to thin (Fig.32e);

d) Streamlined angular junctures, Fig.32f fulfills this requirement, while Fig.32g does not.

The Method of welding together several castings, or welding a forged with a rolled product is advisable, if: a) it is not possible to cast the product as one piece, particularly, if the foundry furnace or the crane lack the ability and power

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required, b) if by casting, individual elements of the product can be made simple, for example, by casting separately segments of a bulky, space consuming stator of a hydro-turbine (Fig.33a), namely, ring (1) and columns (2) (Fig.33b). Another example is: two castings suitable for machine shaping after being welded together instead of one casting which by necessity must be shaped by hand, c) if the quality of individual segments, as compared with the quality of the product cast as one piece, will be improved. For example, castings of certain grades of austenite steels, where the additional welding-of castings operation will be compensated by the decrease of time spent in repairing the metal defects which occur very often in such steels, d) if it will result in a decreased cross section and smaller weight of the entire product, e) if badly cast segments of a large product can be substituted by rolled segments; for example, the thin bottom of a large gear box (Fig.33c) is substituted by a plate (Fig.33d).

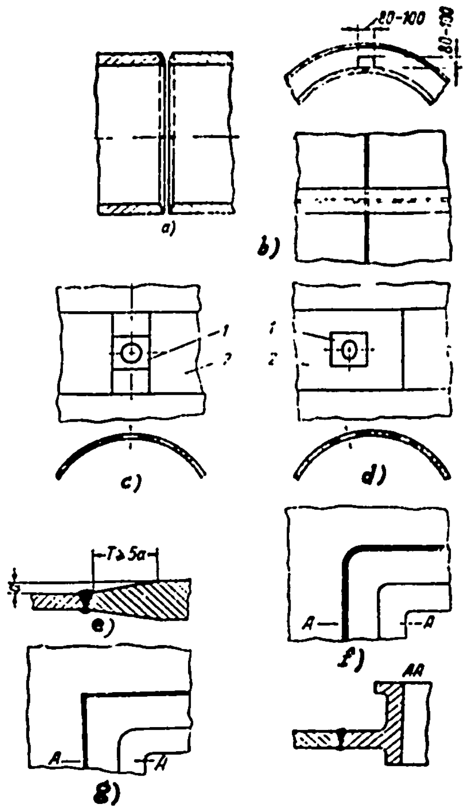

Fig.32 - Design Features of Large Welded Products Having Thick Walls

In the welding of castings, provision should be made for added metal at the welded places to take care of casting crusts or peelings. In carbon steel castings the carbon content should be limited to 0.25 - 0.30% with the object to be able to weld without a preheat. The castings should be designed with the aim of equal cross sections at the welded joints. In the welding of castings, alongside with the manual electric arc welding, automatic electric arc welding is also used. The most effective methods in the making of products from welded castings are electro-slag and termite welding methods, which are also effective in the welding of forgings, thereby helping to lighten the load of heavy hydraulic forging presses.

Automatic and Semiautomatic Welding under a Flux. The Thickness and the Technological Process of Welding (see earlier in text) determine the method of preparing the borders and edges for welding. Aluminum sheets up to 20 mm thick are welded without beveling the edges.

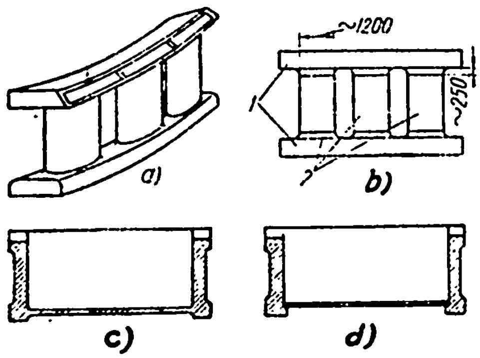

Fig.33 - Samples of Welded-Casting Designs

The Seam in Space may be in the low position or at an angle up to 3°.

The outline of the seam in automatic welding may be circular or rectilineal; in semiautomatic welding any outline is practical. Interrupted seams are usually welded semiautomatically.

The Productivity of Automatic Welding may be Increased (mostly by spending less time on other operations) by: a) having welding joints of the same type. For example, the design of Fig.34a does not

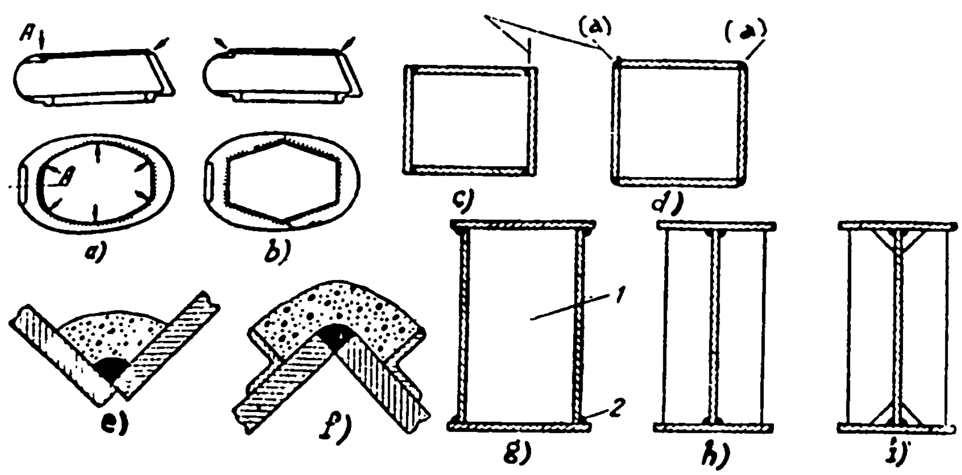

Fig.34 - Features of Assemblies Welded Automatically with the Use of Flux.

(a) Position of automat axis in welding

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fulfill this requirement because segment A has a butt joint and the other segments have overlapping joints; besides, the welding of the curved seams with their complex joints is made difficult; by designing the piece in accordance with Fig.34b, these defects are eliminated; b) by a seam location requiring a minimum adjustment of the welding equipment and a minimum of edging operations; for example, the design as in Fig.34c requires one edging operation without any adjustments, while the less successful design of Fig.34d requires many adjustments for the same number of edgings; c) by making the flux easy to remain in its place, for example, the joints in Fig.34e and the similar joint (Fig.34f) require special devices to retain the flux; d) by making an unobstructed movement of the automat along the seam possible. Example: the box-like shape of the beams with inside diaphragms (1) in Fig.34g allow an uninterrupted outside welding of the belt seams (2); the double-T design of Fig.34h is less convenient; this inconvenience may be remedied by welding ribs with angles cut off after the welding of the belt seams (Fig.34i).

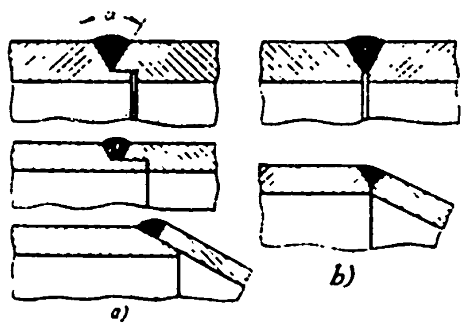

Fig.35 - Variety of Joints in Automatic Welding with Flux of Small Products

<u>The Minimum Diameter of a Product</u> which will permit the inside welding of longitudinal and circular seams with ordinary automatic equipment is 800 mm.

<u>The Minimum Diameter of Outside Circular Seams</u> in automatic welding with flux is about 100 mm. If the use of steel, copper or flux linings is not feasible, due to the small size of the product, the joints should be so designed as to prevent the molten metal from flowing out. The design of Fig.35a fulfills this requirement, the design of Fig.35b does not. The depth of penetration, when welding circular seams in small products, is decreasing; this calls for a widening of the

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groove at an angle of up to 90°, or the widening may have the shape of a trapezoid (Fig.35a).

Electroslag Welding. Butt joints are the type of welding by this method. The

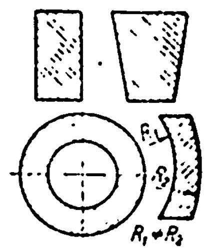

Fig.36 - Types of Cross Sections of Parts Welded by Electroslag Method

edges are either shaved by a planer or cut by a gas-cutting automat without bevels. The welded parts are assembled with a clearance of 22 - 30 mm. The thickness of steel may be 50 - 250 mm and higher. The edges should not be displaced by more than 3 - 4 mm during the assembly of parts.

The type of cross sections of the welded parts are: rectangular trapezoid, circular or profiled surrounded by circular arcs (Fig.36).

The Position of the Welded Seams is vertical or nearly vertical and also circular. Circular seams are welded with the aid of a copper ring, cut into seg-

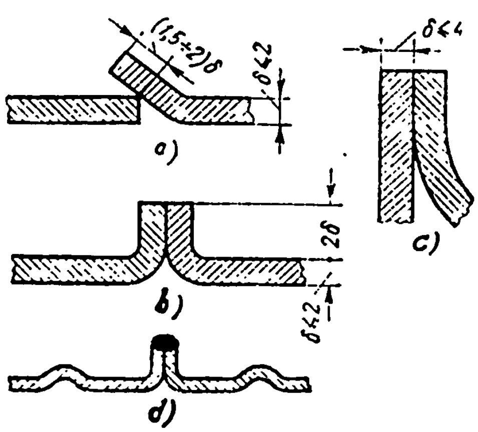

Fig.37 - Designing of Joints for Gas Welding

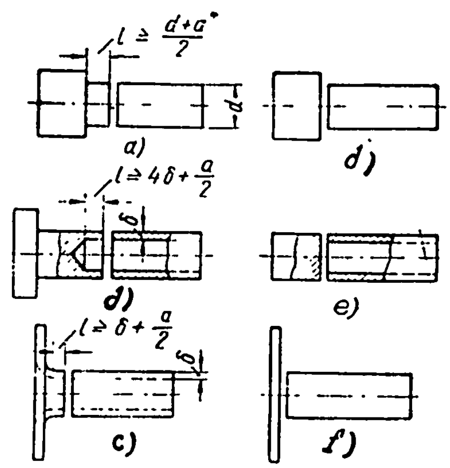

Fig.38 - Butt-Welded Joints

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ments, cooled and acting as an underliner. If sufficiently thick, a steel ring may also be used as an underliner.

Gas and Electric Arc Welding with Gas Protection. In Gas Welding it is better to make a butt joint with bent edges. This will insure the welded parts with the same degree of heating and deformation. Edge bending of one of the parts (Fig.37a), or of both parts (Fig.37b) is used when $\delta \leq$ 2mm; a junction with a bent edge (Fig.37c), when the thickness $\delta \leq$ 4 mm; a butt joint without beveling the edges is made when $\delta \leq$ 5 mm; a butt joint with a V-shaped cut is made when $\delta \leq$ 5 mm. Thin parts are often welded in T-shapes. Parts made of light alloys are sometimes going through a zigzag device to avoid warping (Fig.37d).

In the Electric Arc Welding with the use of a nonmelting electrode with gas protection the usual kind of joints are butt joints with bent edges. In the welding with a melting electrode, T-shaped joints are also used in addition to butt joints with edges bent. In the first case (nonmelting electrodes) the edges are prepared the same way as in gas welding; in the second case (melting electrodes) as in ordinary electric arc welding.

Contact Butt Welding and Gas Pressure Welding. The Cross Sections near the joints should be the same for each of the welded parts, so that each part will be subjected to the same rate of heating and to the same rate of plastic deformation at the end of the welding. The designs shown in Fig.38, a-c fulfill this requirement and the designs of Fig.38, d-f do not. If a is the general shortening of the parts in welding, then, depending on the cross section, a in contact welding will be a = 8 - 50 mm (usually 10 - 20 mm). In gas-prsssure welding, a = 10 - 30 mm (for round parts, a ≈ 0.3 d). To avoid an unequal heating of the parts they should not differ, dimensionally, by more than 15%, as measured by the diameter of round pieces and by the wall thickness of pipes, and should not differ by more than 10%, as measured by the side of a square piece. In the contact method of welding, the butt ends are usually flat. In the gas-pressure welding of pipes with walls

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thicker than 3 mm, it is desirable to bevel the edges and have them spread on the outside by a total of 20 – 40%; in other cases, no beveling is used.

Rings or round objects may be welded with one joint if the ratio of their inside diameter to the diameter or thickness of the product is greater than 10. Other round objects, for example chain links of more than 20 mm in diameter, are welded with two joints (two half-links).

Spot Welding. The Size (Diameter) of Welded Dots is determined by the diameter of their internal nucleus molten during the heating. Its size depends upon the rate of heating, i.e., upon the conditions demanded by the process. With properly selected conditions (see earlier in text) the diameter of a welded dot may be

Table 30

Distribution of Dots in Spot Welding of Steel Parts

Thickness of One Part in mm	Recommended Minimum Distance between Two Dots in mm		Minimum Distance from Center of Dot to the Edge of the Part in the Direction Perpendicular to the Acting Force in mm	Minimum Distance from Center of Dot to the Ribs and Bent Edges in mm
	When Two Parts are Welded	When Three Parts are Welded		
1	15	20	6	8
2	25	30	9	12
3	30	40	12	18
4	40	50	14	25
6	50	70	16	30
8	80	100	20	40

Remarks: 1. The minimum distance from center of dot to the edge of the part in the direction of the acting force should not be less than $2d_m$ for a singly cut dot, and not less than $3d_m$ for a doubly cut dot, where d_m is the calculated diameter of the welded dot.

2 Spot welding of parts thicker than 6 mm is possible only with special equipment.

assumed to equal $d_m = 2 + 3$ mm, where δ is the thickness of the thinnest of the welded parts, in mm.

The Positioning of the Dots is subject to the following: in the placing of a row of dots, a part of the current is shunted through the previously welded dot; the smaller the distance between two dots, the greater the rate of shunting and the size-stability of the dots is less. When the distance of the dot to the edge is small, it will result in an impression in the molten metal near the edge with a deep dent in the welded part and a lower strength of the joint. It will be hard to get a good contact between the welded parts, if the dots are welded near ribs or near other portions servnng to strengthen the product. Instructions how to distribute the welding dots are given in Table 30.

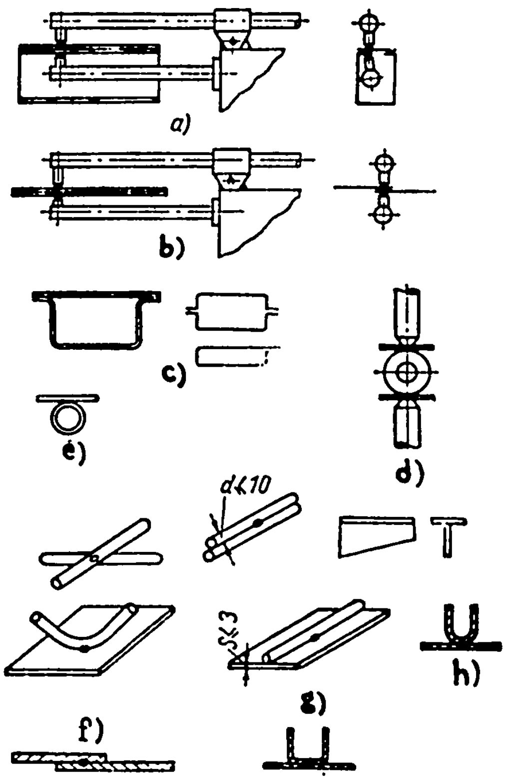

Fig.39 - Features in Spot-Welded Assemblies

Designing Welded Assemblies. The design of welded assemblies should provide for the following: a) a minimum of ferromagnetic parts, if these are to be a part of the machine welding circuit; when such parts shift their place in the contour, the resistance and current also change and the results become uncertain. Example, the designs in Fig.39a and b are less satisfactory than the design shown in Fig.39c; b) provisions should be made to supply the electrodes with the required force without a considerable deformation of the assembly. Example, the welding of thin sheets with a thick-walled pipe (Fig.39d) is possible, whereas it is impossible with a thin-walled tube (Fig.39e) where the small diameter of the tube will not allow the entrance of the electrode; c) provision should be made to insure a

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free local deformation of the welded part in the zone of the welded dot. Example, the joint shown in Fig.39f fully satisfies this requirement; the joint shown in Fig.39g only partially solves the problem and the joint in Fig.39h does not solve the problem at all.

Roller Welding. Types of joints welded by this method are shown in Fig.40, where a shows a lap-joint and b a joint with edges bent. The minimum size of a which is the size of the overlap or of the bend is as follows:

Thickness of one sheet in mm	a in mm
0.25-0.5	10
0.75-1	12
1.5	15
2	18
3	20

When the electrodes are wide and the overlap reduced to $(3 - 4)\delta$, the edges of the welded part should be flattened to a thickness about equal to δ. (Fig.40c). The unfavorable features of this type of joint are the lowered strength and the wear of electrodes; the favorable side is the smoothness of the surface which allows a quality finishing.

Relief and T-Shaped Welding. In a Relief Welding, in one of the welded parts there should be stamped-out places which will determine the places for the welding dots. (The sizes of these contact points are shown earlier in text.) The number n of simultaneously welded dots (the number of contact points) depends upon the thickness of parts and upon the power of the welding machine, n = 2 - 4, with thin parts, n may reach 8 - 12. The minimum distance between the contact points is 2.5 D; from the edge to the contact point is 2D, (D being the diameter of the contact point).

T-Shaped Welding is used for joining of parts with sharply different cross sections (Fig.41). When the butt ends are flat (Fig.41a and b) not all cross sections can be welded. As a remedy, one of the parts has stamped-out, or machinically made, contact points (Fig.41 c-f) which localize the heating and the welding

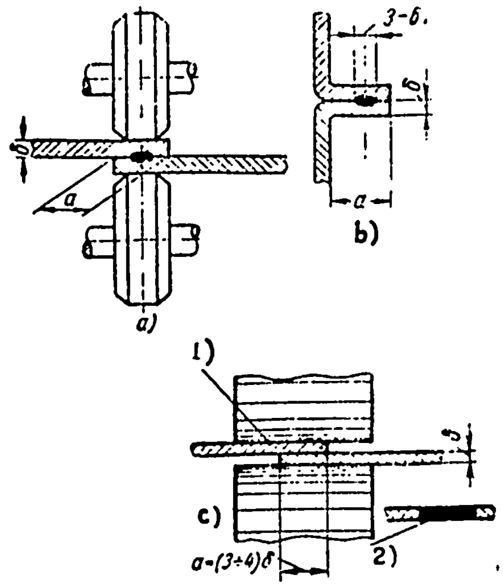

Fig.40 - Types of Joints in Roller Welding

1) Before welding; 2) After welding

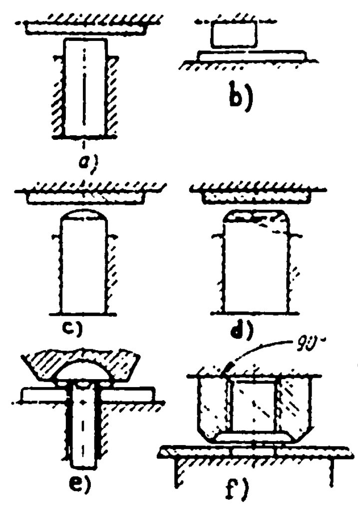

Fig. 41 - Samples of T-Shaped Weldings

in places requiring a solid joint, (welding of an edge to a tank, Fig.41f), or where the greatest strength is required (welding of a pin and welding of a bolt, Fig.41d and e).

The area of a welded joint in T-shaped welding usually does not exceed 100 - 150 mm^2. The area of contact of welded parts may be several times as large as the area of the welded joint.

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